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THE CLINICAL USE OF
PRISMS

MADDOX

A 28.F.1889.3.



Charles A. Oliver.

THE CLINICAL USE OF
PRISMS;

AND THE

Decentering of Lenses.

BY

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Late Syme Surgical Fellow, Edinburgh.

Bristol :
JOHN WRIGHT & CO.
London :
HAMILTON, ADAMS & CO., PATERNOSTER ROW.

1889.

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PREFACE.

THE title of this little work indicates its chief features, but does not cover its ground completely. Its first object was to communicate a series of aids to precision in the use of prisms, worked out during several years, which it is hoped will be of some service in this difficult by-way of ophthalmic practice. They have, however, been introduced by a sketch of the simplest properties of prisms, and supplemented by a brief account of their chief clinical uses. For the sake of brevity, results are given rather than the geometrical processes by which they were obtained, while the mathematical formulæ are either suppressed or relegated to foot-notes. When possible, home-made appliances are suggested in preference to expensive apparatus. Some failure in prescribing prismatic spectacles and combinations has perhaps

arisen, in the past, from the lack of precise methods and tables to work by ; encouraging exceptions must stimulate the desire to extend their number, but it will not be supposed that the precision aimed at in these pages is necessary in the majority of refraction cases. It is chiefly anomalies of convergence, faulty tendencies of the ocular muscles, and the needs of the increasing neurasthenic class of patients that are kept in view. In these last cases, spectacles cause discomfort, however perfectly refraction may be corrected, unless the lenses are also suitably placed in respect of convergence, and sometimes even then, for a time.

Part of the manuscript was kindly read over by my friend, Dr. POULETT WELLS, to whom I am indebted for one or two valuable corrections, and, indeed, for suggesting the need of a book on prisms.

July, 1889.

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PART I.—PRISMS.

A.—SIMPLEST PROPERTIES OF PRISMS.

I.—GEOMETRICAL PROPERTIES.

IN Ophthalmology, as in Optics, the essential thought of a “prism” is a wedge of transparent material, having at least two *plane* faces parted by an angle.

This angle may be of any size, and is spoken of as the “*angle of refraction.*”

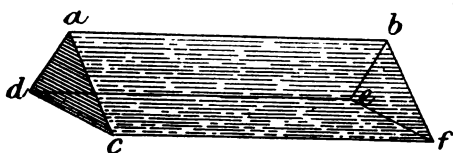


Fig. 1.—A rectangular prism.

In *Fig. 1* we see the prominent features of a rectangular prism — the kind most commonly used by students of optics. The “*refracting angle*” is $d a c$; the plane faces, $a b d e$ and $a b c f$ are named “*refracting surfaces,*” and the line $a b$ in which they meet, or would meet if prolonged, is called the “*edge.*”

The sections $a d c$ and $b e f$ being made in planes perpendicular to the refracting surfaces, are named "*principal sections*" The remaining surface $d c e f$ is the "*base*."



Fig. 2.—The same prism in section.

When prisms are designated "square," "rectangular," "circular," and so forth, it is of course understood that these expressions do not, as indeed they could not, apply to the angle of the wedge, but to *the shape of the two refracting surfaces*. Clinical prisms are almost universally circular to admit of their insertion in the same trial-frame as the lenses: the design in Fig. 3 shews how a circular prism is related to, as though it were cut out of, a rectangular one.

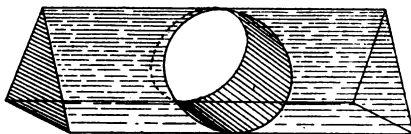


Fig. 3.—A hypothetical illustration to shew the relation of a circular prism to a rectangular one.

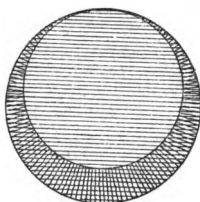


Fig. 4.—A circular prism.

2.—OPTICAL PROPERTIES OF PRISMS.

When rays of light traverse a prism they undergo “refraction,” by which they are bent from their previous course and emerge in a new direction. In *Fig. 5* this is illustrated.

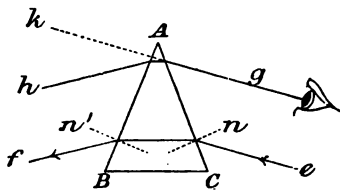


Fig. 5.—Refraction through a prism. Incident ray *e*; emergent ray *f*; incident ray in opposite direction *h*; emergent ray *g*.

An “incident ray” (*e*) is seen to impinge on the face *AC*, but here in passing out of the less refracting medium—air—into the more refracting medium—glass—it is bent *towards* the dotted line *n*, which, being perpendicular to the surface, is called the “normal.”

The ray, after traversing the prism, emerges

from the other face $A B$, but since, while doing this, it is now again entering the less refracting medium, it is bent *away from* the normal, n' . The ray thus experiences a double deflection, the combined effect of which is that it is turned from its previous course through an angle about half that by which the refracting surfaces are separated. It is important to notice that since the deflections take place only at the surfaces, the thickness of the prism, or the distance from its edge at which it is traversed by the ray, does not affect the result, provided the angle between the surfaces remains unchanged. Thus in the figure, the rays $g h$ and $e f$ are equally deflected, though the former is much nearer the edge of the prism than the latter : the greater the angle ($B A C$) between the faces, the greater is the deflection of both rays.*

MINIMUM DEVIATION.—When the points of incidence and emergence of a given ray are equi-distant from the edge of the prism,

* For the index of refraction, the law of sines, etc., the reader is referred to the text-books. Their study is not essential for our subject.

as in the figure, the *ray* is said to traverse the prism in the "direction of minimum deviation ;" or, to put it another way, the *prism* is said to be (in reference to the ray) in its "position of minimum deviation." By this it is meant that the ray under these conditions suffers less total deviation than if it passed through the prism in any other direction.† With weak prisms, however, and only slight departures from the "position of symmetry," the difference is so trifling that it may be neglected in ophthalmic practice.

DISPERSION.—By dispersion, or "chromatic aberration," is meant the breaking up of light into its constituent colours. It is a property possessed in greater or less degree by all prisms, since the differently coloured rays, being unequally refrangible, are deflected

† This is beautifully defined, in an experimental way, by Deschanel : "When a beam of sunlight in a dark room is transmitted through a prism, it will be found, on rotating the prism about its axis, that there is a certain mean position which gives smaller deviation of the transmitted light than positions on either side of it : and that when the prism is in this position, a small rotation of it has no sensible effect on the amount of deviation. The position determined experimentally by these conditions, and known as the position of minimum deviation, is the position in which the ray passes symmetrically."

through different angles, the violet rays (or more correctly the lavender, if they are really part of the spectrum) experiencing the greatest deflection, and the red the least, while the paths of the rays of intermediate colours are spread out between these two extremes. The whole solar spectrum can thus be received upon a white screen arranged to intercept a pencil of light which has traversed a strong prism. This property of dispersion, so valuable in spectrum analysis, and to which also are due the various tints of dawn and sunset, is a serious disadvantage in the ophthalmological use of prisms, from the coloured margins it appears to give to objects, and the want of definition it occasions, just in proportion to the strength of the prism used.

It is only fairly weak prisms, therefore, that can be clinically employed with much advantage. The dispersive power of crown glass is so much less than of flint glass that it is invariably employed for clinical purposes. Achromatic prisms can be made by cementing together two prisms, one of crown, the other of flint glass, with the apex of one to the base

of the other, since the ratio between the refractive and dispersive power is different in the two kinds of glass.* But though suggested long ago, such combinations have been precluded by their weight from clinical use.

3.—CLINICAL PROPERTIES OF PRISMS.

The only clinical use of prisms is to change the direction of the rays of light, but this is fruitful in its secondary applications. They always produce an optical illusion; in other words, they make objects appear in a different position from that which they actually occupy.

Clinical prisms, as we have seen, are generally circular; their thinnest point is called the "apex," and their thickest part the "base."

An imaginary line between the apex and base is called, for convenience, the "*base-apex line*." All objects viewed through a prism appear displaced in a direction parallel to this

* The dispersive power of crown glass is to that of flint glass as 33 to 52; whereas the refractive power is about as 31 to 32, though it varies greatly with different specimens, and must be determined for each.

line, and *always towards the edge*, by which is meant the line in which the two plane surfaces would, if prolonged, meet. It is customary to say that objects appear displaced towards the apex, an expression which, if a little less correct, is still very convenient, provided it is not misunderstood. The accompanying diagram (*Fig. 6*) will make it clear, and a

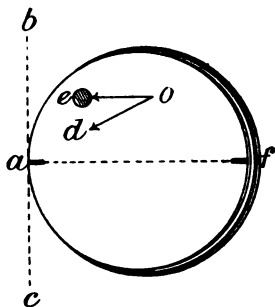


Fig. 6.—To shew how an object at *O* appears displaced, not in the direction *d* towards the apex *a*, but in the direction *e* towards the edge *b c*, and parallel to the “base-apex line,” *a f*.

glance back to *Fig. 3* may assist in understanding what is meant by the “edge,” for since the refracting surfaces of the rectangular prism are extensions of those of the circular one (supposing the latter to be in place) the line in which they meet is the “edge” of both prisms. Thus, to give an experimental example, if we look at a vertical line on

the wall, as xx in *Fig. 7*, through a prism

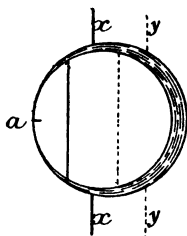


Fig. 7.—To shew the apparent displacement of lines through a prism.

held several inches from the eye, with its apex at a , we observe that the part of the line seen through the prism appears displaced towards its edge. The reason is apparent from a glance at *Fig. 5* (on p. 9), where the ray $h g$ from an object at h is deflected by the prism towards its base, so that it appears to come from k ; or, in other words, it enters the eye in a direction as if it came from k , so that the object is mentally projected there. Since the refracting surfaces of any prism are of necessity inclined to each other by the same angle in every part of their area, it follows that the apparent displacement of an object is equally great, through whatever part of the prism it is viewed. Thus in *Fig. 7* the lines xx and yy appear equally

displaced. By this property prisms may be at once distinguished from lenses, or combinations of lenses and prisms. With a lens, lines viewed through different sides of its optical centre appear displaced in opposite directions; with a concave lens, both lines appear deflected towards the centre, and with a convex one both away from it. As regards *direction* of displacement, the edge of a convex lens is well known to act like a prism with its edge outwards, while that of a concave lens acts like a prism with its edge inwards, though in each case the *degree* of displacement increases with each approach from the centre to the edge. By viewing a distant line through an unknown lens, held by its edge, and opposing to it lens after lens from the trial case till the line appears unbroken, the strength of the unknown lens can be determined to within a quarter of a diopetre, and the same principle is utilised in the now general practice of viewing some object through a moving lens, to observe whether the apparent movement of the object is with or contrary to that of the lens, which in the former event is concave, and in the latter convex.

To return to prisms, we have seen that they appear to *displace objects in the direction of their edge*. Since an eye tends to be diverted towards the (apparently) new position of the object, it follows that *the line of fixation is also displaced towards the edge*, and in working with prisms these two clinical properties are all that need be remembered. *Fig. 8* illustrates both: a

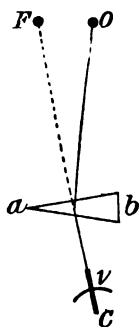
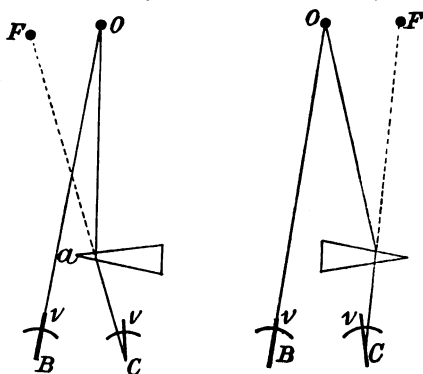


Fig. 8.—A prism before an eye, in monocular vision.

prism is placed before one eye, *the other being covered*, and it is evident that the object *O* appears displaced to *F*, and the line of fixation *v* is diverted from *O* to *F*,—both in the direction of the apex *a*. The line *FC* in which the false image lies is called the “line of projection,” since it marks the direction in

which the picture on the retina is mentally projected.

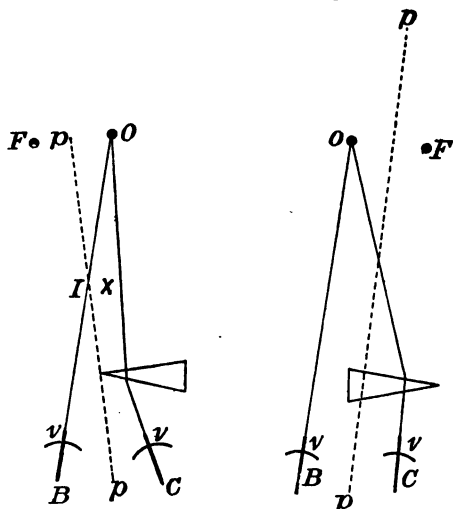
With binocular vision, as in *Figs. 9 to 12*, the conditions are not quite so simple. In all these figures the ruled lines shew the actual course of the rays from the object *O*, and the dotted lines are the lines of projection. They almost explain themselves: in all it will be seen that the object appears displaced towards the edge of the prism, though in some (*Figs. 9 and 10*) there is



Figs. 9 and 10.—Prisms not overcome, and therefore causing diplopia.

diplopia, since the object is seen in its true position *O* by the unclad eye at the same time that its false image *F* is seen by the other in the direction of the edge of the prism,

which is directed inwards in *Fig. 9*, and outwards in *Fig. 10*. In *Figs. 11* and *12*



Figs. 11 and 12.—Prisms overcome ; no diplopia.

there is no diplopia ; it has been corrected by the desire for single vision, and the two images are fused into one. Still, the united image appears in a false position, though the angular displacement of the line of projection $p\ p$, is only half that in the previous examples. The diplopia is corrected by a rotation of the eye so as to receive again upon its fovea centralis the picture of the object which the prism had dislodged to another part of the retina ; thus in these two

figures the line of fixation $v C$, has come to be in line with the rays of light coming through the prism from the object, and since both eyes receive a picture on the fovea, vision is single. In *Figs. 9* and *10* there is *no* definite line of fixation for the right eye, since it is fixing nothing, and it is clear that the picture must fall on the retina away from the fovea, though with every effort to unite the images and bring the axis of vision $v C$, into the line of the rays, the position of the picture on the retina will vary, and the images will move towards or from each other.

Prisms set with their edge inwards as in *Figs. 8, 9, and 11*, are called *adducting prisms*, and those with their edge outwards as in *Figs. 10 and 12*, are called *abducting prisms*. The former, when vision is binocular and without diplopia, by increasing the necessary convergence of the eyes, make objects appear nearer than they actually are, and the latter make them appear too far away. Thus in *Fig. 11* the real object O , appears to be at I , where the two lines of fixation intersect.*

* Exceptions to this I have pointed out in *Journal of Anat. and Phys.* vol. 21, p. 21, but it is not desirable to enlarge on it here, or to enter deeply into the physiology of convergence, which would need a book to itself.

As Hering has shewn, convergence occurs as if for the cross and both eyes are turned towards *I* by an impulse of the conjugate innervation which turns the two eyes to the left: it is the mental cognizance of *this* effort which imparts corresponding obliquity to the line of projection, *p p*. The prism, therefore, does not test the strength of either rectus, since convergence is a single action affecting both eyes equally, but it estimates by how much convergence can be made to exceed accommodation, or *vice versa*. The two functions are so confederate that there are limits to the amount by which either can be increased or diminished without the other. Prisms should be placed as close as possible to the eye, then their angles of deviation nearly express the diplopia, or corrective squint, they occasion, or the sum of both if both are present.

One of three events therefore may happen on placing a prism before an eye. (1), If vision is monocular, one false image is seen, whose distance from the actual position of the object is unvarying, and dependent entirely on the deviating angle of the prism,

Fig. 8. (2), With binocular vision the prism may be too strong to be overcome, in which case there is diplopia with an inconstant distance between the images, which approach each other spasmodically with every effort to overcome the prism. (3), The diplopia may be overcome and the object appear single, though its position in space is misjudged through an angle practically equivalent to half the deviating angle of the prism.

B.—MARKING THE APEX.

Circular prisms, as usually sold, have their apex and base indicated by a slight scratch from a diamond. It is to be feared, as we shall see, that experimental work with prisms has hitherto been frequently vitiated by the prevalent inaccuracy in marking the apex—a defect to which, as far as I am aware, no attention has yet been called. An obvious consequence of inaccurate marking is that prisms may not be quite squarely set in the trial-frame; yet the slightest departure from precision in this particular alters the experiment. For example, if it be desired to

set a prism of 15° d, with its edge exactly in or out, an aberration of the base-apex line through only a ninetieth part of a circle has the effect of not only lessening in a trifling degree the desired horizontal deflection which it is the aim of the prism to produce, but also of introducing a new and unsuspected vertical deflection of more than 1° . This is shewn in *Fig. 13*, where the actual flame *o*, appears

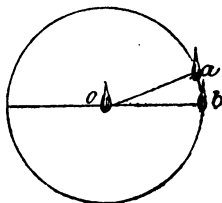


Fig. 13. Shewing the effect of setting a prism by a wrong mark. The marked apex is towards *b*, and the true apex is towards *a*, so that the flame *o*, which should appear at *b*, appears at *a*.

displaced to *a* instead of *b*;—the true base-apex line being *o a*, though the prism is marked as if it were *o b*; hence *a o b* is the angle of error in setting the prism. At twelve feet distant the flame would appear more than two and a half inches higher than it really is.* Now it is well known that

*The unsuspected vertical deflection of a ray of light by a prism whose base-apex line is supposed to be horizontal, or the unsuspected horizontal deflection by a prism whose base-

vertical diplopia greatly embarrasses the neuromotor apparatus, and in some persons it cannot be overcome at all when greater than one degree, so the prism in the previous experiment may be put down with the verdict that it is too strong to be overcome, when really it is the concomitant accidental *vertical* diplopia created by it which cannot be overcome, or at least the effect of which vitiates the experiment.

If any surgeon will take the trouble to test the marks upon his own prisms he will find how frequently they are misplaced ; the test can be easily made by the following simple device. Draw upon a sheet of paper two fine straight lines intersecting each other exactly at right angles as in *Fig. 14*, and hold the prism vertically above them so that on closing one eye the supposed apex apparently coincides with the point of intersection of the lines, and the prism only appears to touch the horizontal line at that point, and does not in the least

apex line is supposed to be vertical, may be found in any particular case, by the following formula, $\sin. x = \sin. D + \sin. r$; where x is the angle required, D is the deviating angle of the prism, and r the angle of accidental rotation from exact rectitude.

overlap it on either side. If the prism is correctly marked, the vertical line appears unbroken as in *Fig. 14*, but if not, the part of the line seen through the prism appears

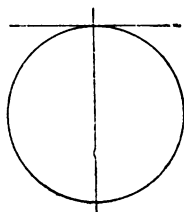


Fig. 14. Mode described for testing the apex of a prism.

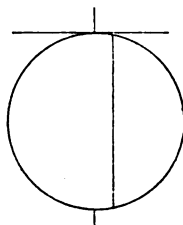


Fig. 15. Appearance with a badly marked prism.

disjointed from the rest, and displaced as in *Fig. 15*, towards the side of the real apex. It only remains to rotate the prism till the unbroken appearance of *Fig. 14* is gained; then the point on the prism's edge in apparent coincidence with the point of intersection of the lines may be regarded with confidence as the real apex. The cross lines can be permanently provided on a large card suspended upon the wall of the consulting room in connection with that for testing the deviating angle, and they will be found useful for many purposes. For opticians it is suggested to have a diamond half embedded in a plate of

glass fixed horizontally above cross-lines similar to those already employed, or merely above one vertical line if the horizontal one be graven on the glass. The diamond would be brought in correspondence with the point of intersection of the lines, so that after finding the apex a slight push of the prism would mark its true position.

A still better form of the apparatus would be one with two shoulders cemented on the glass plate, to grip the edges of the prism instead of using a horizontal line, and to have the diamond held in a sliding arm to make a perfectly straight scratch. Greater distance of the prism from the vertical line magnifies the phenomenon, and makes the test more delicate. The true base of a prism can be found and marked in just the same way as the apex, and if prisms thus manufactured come into use, one of the many causes of experimental inaccuracy will be removed.

C.—PRISMETRY.*

For measuring the refracting angle of a prism (that is, it will be remembered, the angle by which its refracting surfaces are parted), several instruments exist already, named Goniometers,† of which it is easy to make

* This name will be given to the measurement of the deviating angle of prisms ; that of Goniometry being already applied to the measurement of their physical angles.

† A home-made Goniometer for clinical prisms can be easily made by mounting a prism-holder (a lens-holder will do) by a pivot on the centre of a small circular dial of wood ; a long-hand of a clock is fixed to the upright pivot of the prism-holder, and the dial is graduated with degrees, or simply fitted with a common protractor as found in any box of mathematical instruments. The procedure is as follows : Place the prism to be tested in the holder, with base-apex line horizontal, and support the whole instrument on a table or stand opposite the window. Now set the indicating clock-hand at zero of the scale, and rotate the dial itself till a vertical sash of the window, as seen reflected from one face of the prism, appears (to an eye placed between the prism and the window, but lower than the former,) exactly to coincide with a chosen spot or line on the opposite wall. Now, leave the dial *in statu quo*, but rotate the clock-hand till the same window-sash is seen reflected from the other face of the prism, and is brought in line as before with the other two points. The index-hand will now be found pointing to the degree on the scale which describes the refracting angle. The only precaution necessary is to be sure that the observer's eye occupies the same position in making the two observations. Another way to measure the refracting angle is to adapt the legs of a pair of compasses

an adaptation suitable for ophthalmological prisms. But these acquaint us only with the geometrical—not with the optical properties of prisms; what the surgeon needs alone to know is not their refracting angle, but their deviating power over a beam of light. It has been noticed already that this “angle of deviation” is in each case about half the angle of refraction—with weak prisms rather less, and with strong ones rather more, than half (DONDEERS),—but apart from this difference, and from the uncertainty of always in practice ensuring the exact position of minimum deviation, the refractive index of

to the two faces of the prism, then either use a protractor, or measure the distance between the points of the legs, by placing them on a millimetre rule. If the length of the legs is known, the angle required is found by dividing the length of the legs by half the distance between their points, and doubling the angle of which this is the sine. But the dial mode first described, or that with the protractor, needs no calculation. Having thus, by one or other way, measured the refracting angle A , we may measure the deviating angle D , by one of the modes given in the text, and then ascertain the refractive index of the glass of which the prism is composed by dividing the sine of half the sum of the two angles by the sine of half the refracting angle.

$$\text{Thus :} \quad \mu = \frac{\sin. \frac{A + D}{2}}{\sin. \frac{A}{2}}$$

different specimens of crown glass varies so much that, as Donders* truly observed of the angles of deviation, "If we wish to know these accurately, it is necessary to determine the deviations for each glass separately." To do this with certainty and ease two simple methods were contrived some years ago, one most suitable for the student or surgeon, the other for the optician. The first can be made without expense, and employed without artificial light. It consists simply of a strip of cardboard suspended horizontally near the right-hand corner of a consulting-room wall, and at such a height from the floor as to be about level with the eyes of the observer. On the wall adjacent to that on which the cardboard is hung, and which enters into its right-hand corner, a permanent mark is made at the distance most generally convenient for making the observations. The card itself is marked, as in *Fig. 16*, in degrees† for this

* "Accommodation and Refraction of the Eye" (Sydenham Society, p. 132).

† Really, of course, in tangents of degrees. A paper scale of this kind was affixed in May, 1886, to the wall of Messrs. Pickard and Curry's workshop, having been sent them by the author for measuring the deviating angles of their prisms.

distance. All that is necessary to measure

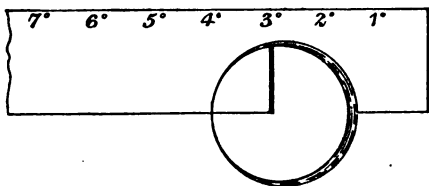


Fig. 16. The author's first mode of prismetry.

the deviating power of a prism is to hold it opposite the already mentioned mark on the wall* with its apex to the left, and so that its upper border appears just beneath the line of degrees as in the figure. The vertical border of the card appears necessarily displaced towards the edge, and points upwards to the number which expresses in degrees, at once and without calculation, the required deflecting angle of the prism. In the figure this is seen to be 3° . One precaution alone needs to be observed ; if the lower edge of the cardboard seen through the prism appears disjointed from the level of the rest, as in *Fig. 17*, the apex of the prism is not pointing exactly to the left, but is either too high or too low, according as that part of the broken line seen through

* The distance of the observer's eye behind the prism does not affect the result in any way.

the prism is above or below the remainder.

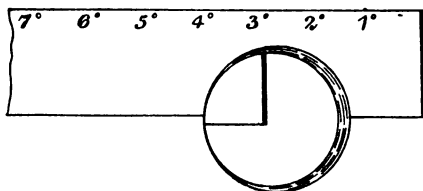


Fig. 17. A prism not held truly.

A slight rotation is therefore necessary to correct this, till the lower border of the card-board appears at one level, as in *Fig. 16*.

The distances between the degrees of the card depend, of course, on the chosen distance at which it is found most convenient to hold the prism, and this would depend on the size of the room and other conditions. The distance of the observer's eye from the prism is of no consequence ; any student can easily mark a piece of cardboard for himself from the accompanying table which gives the distances from the right-hand border of the card at which the several degrees are to be marked upon it, assuming the prism to be held at a uniform distance of six feet (first column), or two metres (second column).

TABLE I.

For marking a card in tangents of degrees at 6 ft. (column A); or 2 metres (column B).					
	A	B		A	B
1°	1'25 in.	3'49 cm.	9°	11'4 in.	31'29 cm.
2°	2'5 "	6'98 "	10°	12'6 "	34'73 "
3°	3'7 "	10'467 "	11°	14'0 "	38'16 "
4°	5'0 "	13'95 "	12°	15'3 "	41'58 "
5°	6'3 "	17'43 "	13°	16'6 "	44'99 "
6°	7'57 "	20'9 "	14°	17'9 "	48'38 "
7°	8'84 "	24'37 "	15°	19'3 "	51'76 "
8°	10'12 "	27'83 "	16°	20'64 "	55'13 "

For a different range, the measurements would of course differ in proportion ; thus, should it be decided to always hold the prism at 3 feet, the distances would be half as great as in the table ; if at 12 feet, twice as great. It is clearly an advantage, when a patient enters with prismatic spectacles, for the surgeon to be able to ascertain their strength without calculation or artificial light ; and such spectacles will no doubt come into more frequent use, since convergence is becoming more precisely studied.

The second method affords a much prettier *demonstration* of the deviating angle of prisms, but needs a more definite illumination than diffused daylight. It consists of a strip of

wood, as in *Fig. 18*, laid flat on a table or coun-

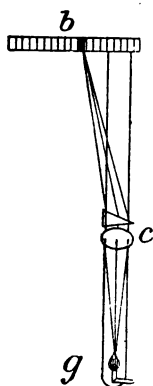


Fig. 18. Second mode of prismetry.

ter with a shorter strip *b*, fixed at right angles to its further end in such wise that while horizontal in its length its plane is vertical. Upon the longer strip a cylindrical lens *c*, is fixed erect, with its axis vertical, so as to throw a line of light from the gas flame *g* upon the strip *b*, which is marked in degrees* so that a prism held before the cylinder *c*, with its base-apex line horizontal, at once makes the bright line move to that degree which indicates the deviating angle. The flame can either be fixed to the main strip or be quite separate, and it is well, if the light is

* Strictly speaking, "in tangents of degrees."

poor, to combine with the cylindrical lens a spherical one of such strength that the source of light shall be at its principal focus.*

An important proposal has been made by Dr. Edward Jackson, of Philadelphia, that all ophthalmological prisms should be *marked* with the angle by which they deviate rays of light, and, in consequence, it was recommended by a committee of the American Ophthalmological Society in September of the year 1888, that :

* A modification in this method was suggested by Messrs. Pickard and Curry (to whom it was given about the same time as the other), viz. : to curve the graduated scale into an arc, in order to save the calculation of tangents in its manufacture. The following footnote appeared in an essay at the time : "Since the only clinical use of prisms is to deflect the rays of light which traverse them, and since the index of refraction varies with the different specimens of glass, the usual method of marking prisms is not very satisfactory for exact purposes. After consultation with Messrs. Pickard and Curry, they have now a quick method of testing the declinating angle of their prisms" (Journal of Anatomy and Phys., Maddox, Oct., 1886, p. 32).

It will be seen, however, from this extract, that it was only for "exact" (*i.e.* physiological and experimental) purposes that the need was thus expressed for the marking of prisms with their deviating angles. Dr. Jackson's subsequent proposal has prominence given to it in the text, because it embraces all prisms used in ophthalmology : its acceptance by Messrs. Pickard and Curry was due to the energy of Dr. Landolt, last year.

(1,) Prisms ought to be designated by the number of degrees, "minimum deviation," they produce.

(2,) Where intervals of less than one degree are desired, half degrees and quarter degrees should be used.

(3,) To indicate that degrees of deviation are meant, the letter d should be used ; thus prism $2^{\circ}d$ will indicate a prism that produces a minimum of two degrees.

The committee consisted of Drs. E. Jackson, S. M. Burnett, and H. D. Noyes, and their decision was conveyed by Dr. Landolt to the Heidelberg Congress in the same year.

It is almost certain, therefore, that prisms thus marked will soon come into general use. and they will greatly simplify calculation.

Possibly, however, if I may be allowed to suggest it, a still better plan would be to have all prisms marked with metre angles and their fractions, so as to correspond with lenses in the trial case, a metre angle being the chosen unit of convergence just as a dioptré is that of accommodation. The only disadvantage is that the metre angle is an inconstant quantity. It is the angle by which

each eye has converged from direct parallelism while fixing a point in the median line at the distance of one metre. Its size, therefore, depends on the distance of the centre of rotation of the eye from the median plane, for it is this line which subtends the angle. Its average in adults is taken by Nagel as $1^{\circ} 50'$. It is useful to have a scale, as in *Fig. 16*, marked in metre angles according to this average, as well as a scale marked in degrees, so that by holding any prism up to view, its strength in either unit can be seen without calculation.

In Table II the measurements are given by which such a scale can be made by anyone for himself, on a strip of paper or cardboard.

TABLE II.

For marking a card to be used at the distance of two metres, for telling the strength of a prism in metre angles.			
Metre Angles.		Metre Angles.	
0'5 m. a.	3'2 cm.	5'0	32'3 cm.
1'0 "	6'4 "	5'5	35'6 "
1'5 "	9'6 "	6'0	38'9 "
2'0 "	12'8 "	6'5	42'2 "
2'5 "	16'0 "	7'0	45'6 "
3'0 "	19'3 "	7'5	49'0 "
3'5 "	22'5 "	8'0	52'3 "
4'0 "	25'7 "	8'5	55'8 "
4'5 "	29'0 "	9'0	59'3 "

D.—PLANENESS OF SURFACE.

Little need be said of this, though in buying prisms it is well to examine the planeness of the important "refracting surfaces"; it is often very defective, and this slightly contributes to the difficulties of using prisms. Moreover, since plane faces are rarely ground with the same accuracy as spherical ones, it is better when combinations of lenses and prisms are prescribed to have both surfaces spherical instead of one spherical and the other plane, except when very strong lenses are employed, in which case they are better sometimes plano-convex to diminish spherical aberration.

E.—ADJUSTMENT OF PRISMS IN THE TRIAL-FRAME.

If the apex and base of a circular prism are correctly marked, there is no difficulty in setting it with the base-apex line either exactly vertical or horizontal. But if there should be any doubt about their precise position, the following simple expedient will at once enable us to detect and correct any malposition. If the base-apex line is wished

to be horizontal as with the right hand prism of *Fig. 19*, hold the trial-frame a few inches

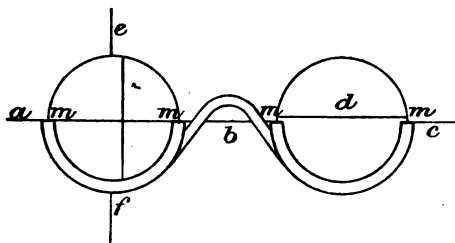


Fig. 19. Two prisms in a trial-frame.

from the eyes, so that, as represented in the figure, the upper extremities *m m m m*, of its sockets coincide to all appearance with a horizontal line *a b c*, upon the wall : if this line upon the wall appears continuous, the prism is correctly set, but if that part of it visible through the prism appears disjointed from the rest as *d* in *Fig. 19*, the apex is either too high or too low, according as the apparent disjointment is upwards or downwards. In the figure the apex is too high and the correction is therefore easily made by rotating the prism so as to depress the apex till the line appears continuous. If the base-apex line is wished to be vertical, as with the left hand prism of the same figure

the horizontal line on the wall must be supplemented by another at right angles to it, as *ef* in the figure: again adjusting the frame as before to the horizontal line of sight, the rectitude of the prism is now indicated by the appearance of the *vertical* line. If *its* course appears undeviating the setting is faultless, but if, as in the figure, the part seen through the prism is dissociated from the rest, the apex is shewn to be too much to the same side, and it therefore needs readjustment.

F.—TEMPORARY TRIALS.

Before prescribing prisms or their combinations, it is well, when practicable, to let the patient wear a trial pair at home for a few evenings first, for sustained action alone affords a true indication of whether they will suit. Prisms and lenses can be bound in an ordinary trial-frame by a strip of gutta-percha,

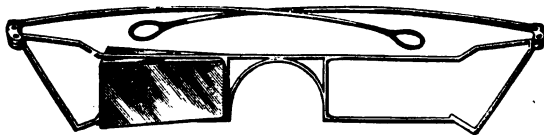


Fig. 20. Rectangular prisms in a frame as suggested in the text. This frame may be obtained from Messrs. Pickard and Curry.

but as accidental rotation is very apt to occur, some other contrivance is desirable when prisms alone are in question. *Fig. 20* represents a device I once suggested* for the purpose of holding *rectangular* prisms, which I find can be made quite as cheaply as circular ones. The small size of the prisms, while yet allowing sufficient lateral range of movement for the eyeballs, would contribute to the manifest desideratum of lightness. No time is wasted in exact adjustment of the prisms, as their shape not only secures a correct position at once, but removes any possibility of subsequent displacement. Each prism has a longitudinal groove in its upper and lower surface, so that it need only be pushed in between the wires till caught by the elbow.

So light a frame as this could be worn *together* with an ordinary pair of spectacles,

*I find since that Mr. Chas. Wray, F.R.C.S., of Croydon, has had a somewhat similar frame made with the addition of a spirit level. Dr. Stevens says, "It is my custom to keep on hand a large number of spectacle frames of uniform size, and a quantity of plain prism glasses of 1° , 2° , and 3° , which can be, without loss of time, slipped into the frames. With these I am able, in a few moments, to arrange temporary prisms for a patient."—(Archives of Oph., June, 1888, p. 184.)

when it is desired to try for a few evenings the joint effect of prismatic and spherical glasses.

These prisms would also be exceedingly useful for those cases of paralytic strabismus in which partial or complete recovery may be expected, and for which prismatic spectacles are prescribed. The necessity, if this treatment of such cases is to be successful, of prescribing weaker prisms as the case improves (for without this they actually retard recovery), makes it desirable to have a set of test prisms, a pair of which can be worn for a few days or weeks, and be exchanged for another pair if they cause discomfort, or when they need to be weakened owing to progressive recovery.

PART II.

DECENTERING OF LENSES ;
AND COMBINATIONS OF PRISMS WITH LENSES.

INSTEAD of combining a prism and a lens, where it is wished to obtain the effect of both, it is very frequently possible to get the same result by simply decentering the lens, a process which, though already well known, may be simply explained.

The “optical centre” of a lens is that point in it traversed by all rays which, after entering the lens, emerge from it in a direction parallel to their former course. * All rays which do *not* traverse the optical centre are bent from their former course to a degree which depends on the distance from this point, at which they pass through the lens—the greater the distance the greater the deflection. In other words, a lens, in every part other than the optical centre, has the effect of a prism upon any

* This one “property” is all that is necessary for our present purpose, hence it is mentioned, instead of giving a correct definition. See footnote, p. 45.

single ray of light,—the effect of a weak prism near the optical centre, and of a stronger and yet stronger one with every further removal from it, and this equally with concave as with convex lenses. It is evident, therefore, that by shifting a lens so as to bring a more peripheral part into use, a prismatic effect can be obtained just as much as if a prism had been cemented to the lens in its former unshifted position. Such displacement of the optical centre can be effected in one of two ways, the prismatic equivalent of which is identical, but each of which possesses an advantage of its own. First, the lens may simply be *displaced* as it is, rim and all, by lengthening or shortening the spectacle-frame ; or, secondly, the frame remaining unchanged, the lens can be *decentred* in its rim as shewn in *Fig. 21*.

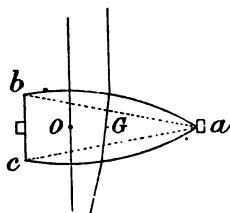


Fig. 21. A decentered lens.

The dioptric strength, or refraction-correcting power, of this lens is exactly the same as that shewn in *Fig. 22*, inasmuch as their surfaces

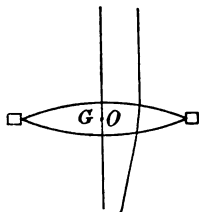


Fig. 22. A lens normally centred.

have the same radius of curvature, but it is as though it were cut peripherally, as shewn in *Fig. 23*, from a larger lens *c d*, so that its optical *O*, and geometrical *G*, centres do not coincide as in an ordinary lens. A brief study of *Fig. 21*, which gives the lens *a b*, of *Fig. 23*

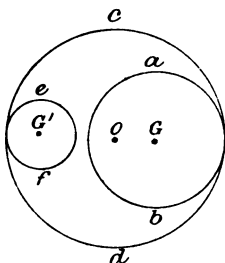


Fig. 23. Peripheric lenses cut out of a larger one.

in section, will show that the effect of cutting it eccentrically out of a larger lens is exactly

the same as if a smaller lens of the same strength had been split to admit a prism between its two halves. Without altering its dioptric power then, a prism has been virtually introduced. The *geometrical* centre of a lens is the point midway between all edges, as *G* in *Figs. 21, 22 and 23*. The *optical* centre on the other hand, lies between all points* on the two opposite surfaces of a lens which are parallel to each other and which therefore have no more prismatic or deviating effect on a ray of light entering by one and emerging by the other than a plate of glass would have. It is needless to say that it lies in the thickest part of a convex lens and the thinnest part of a concave one.† For determining its position in any particular lens, an apparatus will be described further on. A lens is said to be normally centred when the optical and geometrical centres coincide as in *Fig. 22*; but to be decentred when, as in *Fig. 21*,

* Strictly, of course, points cannot be parallel, but only the tangents to the curve at the points. But the text will be easily understood.

† It lies in the principal axis of a lens,—the line joining the two centres of curvature; and divides the line of centres in the ratio of the radii of curvature.

the optical centre O , and the geometrical centre G , are apart, the amount of decentration depending on their distance apart. The two points may be so far removed from each other that the optical centre may come to lie outside the lens altogether. Such would evidently be the case with the small lens $e f$ in *Fig. 23*, since the optical centre is at O . *Fig. 24* shews this small lens in section, and



Fig. 24. A lens with its optical centre O , far outside itself.

it is evident at a glance that opposite surfaces are nowhere parallel, and that one or both of the surfaces would need to be prolonged considerably before any point could be found in the one parallel to a point in the other ; were this done a line uniting the points would pass through the optical centre O . We have seen that the effect of decentering a biconvex lens is equivalent to splitting it into two halves, and inserting a prism between them ($b a c$ in *Fig. 21*). The strength of this virtually interpolated prism depends on, first the amount of decentration, and second the

dioptric strength of the lens. A strong lens needs decentering to a less extent than a weak one to produce the same effect. Table III. not only illustrates this but enables us to find the exact prismatic effect of decentering any lens. All that is required is to fix on the number of millimetres (in the highest horizontal row of figures) by which a lens is known to be decentred, and the prismatic effect is found in the column beneath, opposite the dioptric strength of the lens. Conversely, should it be required to know how much to decentre a given lens in order to combine with it the effect of a certain prism, the eye runs along the horizontal line of angles opposite the known strength of lens till that angle is found nearest to the strength of prism required, when the number of mm. at the head of the column will indicate the decentering necessary.

The word "decentering" is generally applied to the removal of the optical centre away from the geometrical centre of the lens, but we have already said that the prismatic effect is the same if the whole lens, rim and all, be simply *displaced*, as by lengthening or

TABLE III.

	1 mm.	2 mm.	3 mm.	4 mm.	5 mm.	6 mm.	7 mm.	8 mm.	9 mm.	10 mm.	11 mm.	12 mm.	13 mm.	14 mm.	15 mm.	16 mm.	18 mm.	20 mm.	23 mm.	24 mm.	26 mm.	28 mm.	30 mm.	32 mm.
5D	1' 43"	8' 28"	5'	7'	8' 25"	10'	13'	14'	15' 28"	17'	19'	20' 37"	22' 27"	24'	26'	27' 30"	31'	35'	38'	41'	45'	48'	52'	55'
75D	2' 30"	5'	8'	10'	13'	15' 28"	18'	20' 37"	23'	26'	28'	31'	33'	36'	38'	41'	46'	52'	57'	61'	65'	69'	73'	77'
1D	3' 26"	7'	10'	14'	17'	20' 37"	24'	27' 30"	31'	35'	38'	41'	45'	48'	52'	55'	61'	69'	77'	85'	93'	101'	109'	
15D	5'	10'	15' 28"	20' 37"	26'	31'	36'	41'	46'	52'	57'	62'	67'	72'	77'	82'	88'	94'	100'	106'	112'	118'	124'	
2D	7'	14'	20' 37"	27' 30"	35'	41'	48'	55'	62'	69'	76'	83'	90'	97'	104'	111'	118'	125'	132'	139'	146'	153'	160'	
3D	10'	15' 28"	31'	41'	52'	63'	74'	85'	96'	107'	118'	129'	140'	151'	162'	173'	184'	195'	206'	217'	228'	239'	250'	
4D	14'	27' 30"	41'	55'	1' 10'	1' 22'	1' 36'	1' 50'	2' 4'	2' 18'	2' 32'	2' 46'	2' 59'	3' 12'	3' 26'	3' 40'	4' 8'	4' 35'	5' 2'	6' 23'	7' 24'	8' 25'	9' 26'	
5D	17'	35'	53'	73'	1' 26'	1' 48'	2'	2' 18'	2' 35'	2' 52'	3' 9'	3' 26'	3' 43'	4' 1'	4' 17'	4' 35'	5' 9'	5' 44'	6' 17'	6' 51'	7' 24'	7' 58'	8' 31'	
6D	20' 37"	41'	1' 2'	1' 28'	1' 48'	2' 4'	2' 24'	2' 45'	3' 5'	3' 28'	3' 46'	4' 7'	4' 27'	4' 48'	5' 9'	5' 23'	6' 10'	6' 51'	7' 31'	8' 12'	8' 52'	9' 32'	10' 12'	
7D	24'	48'	1' 12'	1' 36'	2'	2' 24'	2' 48'	3' 12'	3' 37'	4' 1'	4' 24'	4' 48'	5' 12'	5' 36'	6'	6' 24'	7' 11'	7' 58'	8' 45'	9' 32'	10' 19'	11' 6'	11' 52'	
8D	28'	56'	1' 22'	1' 50'	2' 18'	2' 46'	3' 12'	3' 40'	4' 8'	4' 38'	5' 2'	5' 28'	5' 56'	6' 24'	6' 50'	7' 18'	8' 13'	9' 6'	9' 59'	10' 52'	11' 45'	12' 38'	13' 30'	
9D	31'	1' 2'	1' 32'	2' 4'	2' 35'	3' 6'	3' 37'	4' 8'	4' 38'	5' 9'	5' 44'	6' 17'	6' 51'	7' 24'	7' 41'	8' 12'	9' 13'	10' 12'	11' 12'	12' 11'	13' 10'	14' 9'	15' 7'	
10D	35'	1' 9'	1' 43'	2' 4'	2' 35'	3' 26'	4' 1'	4' 35'	5' 9'	5' 44'	6' 17'	6' 51'	7' 24'	7' 58'	8' 32'	9' 6'	10' 12'	11' 12'	12' 11'	13' 10'	14' 9'	15' 7'	16' 4'	
12D	41'	1' 28'	2' 4'	3' 45'	3' 26'	4' 7'	4' 48'	5' 23'	6' 10'	6' 51'	7' 31'	8' 12'	8' 52'	9' 32'	10' 12'	10' 52'	11' 32'	12' 11'	13' 10'	14' 9'	15' 7'	16' 4'	17' 45'	
14D	48'	1' 36'	2' 24'	3' 12'	4' 1'	4' 48'	5' 36'	6' 24'	7' 11'	7' 58'	8' 45'	9' 32'	10' 19'	11' 6'	11' 52'	12' 38'	13' 10'	14' 9'	15' 89'	17' 0'	18' 34'	19' 48'	21' 0'	
16D	56'	1' 50'	2' 46'	3' 40'	4' 35'	5' 23'	6' 23'	7' 19'	8' 13'	9' 6'	9' 59'	10' 52'	11' 45'	12' 38'	13' 30'	14' 22'	15' 12'	16' 4'	17' 45'	18' 34'	19' 23'	20' 12'	21' 2'	
18D	1' 2'	2' 4'	3' 6'	4' 8'	5' 9'	6' 10'	7' 11'	8' 12'	9' 13'	10' 12'	11' 12'	12' 11'	13' 10'	14' 9'	15' 7'	16' 4'	17' 45'	18' 34'	19' 23'	20' 12'	21' 2'	22' 1'	23' 0'	
20D	1' 9'	2' 18'	3' 26'	4' 35'	5' 44'	6' 51'	7' 58'	9' 6'	10' 12'	11' 12'	12' 11'	13' 10'	14' 84'	15' 39'	16' 42'	17' 46'	18' 48'	19' 45'	20' 45'	21' 45'	22' 45'	23' 45'	24' 45'	

TABLE III.* Shewing the prismatic effect of decentering any lens.

Procedure.—Find the dioptric strength of the lens in the left-hand column, the prismatic effect is then found opposite, under the number of mm. of decentering.

* This table is adapted from a thesis in 1884, where it appeared under another title ("Journal of Anal. and Phys.," Vol. XXI, p. 83). It was made from the simple formula: $\tan z = \frac{d}{f}$

z , being the deviating angle of the virtual prism; d , the decentering in millimetres; f , the focal length of the lens in millimetres.

shortening the spectacle frame; in other words, it makes no prismatic difference, so long as the optical centre is moved, whether the geometrical one remains in *statu quo*, or whether it is shifted equally itself. How are we then to decide between these rival modes, in any given case? Decentering of any kind has the disadvantage of being attended with proportionate increase of weight, as much as if a prism were inserted: the lens of *Fig. 21* is very evidently heavier than that of *Fig. 22*. This fault is entirely avoided by the alternative of displacing the entire lens (instead of only decentering the optical centre *in* the lens), but, on the other hand, such displacing entails, beyond certain limits, a limitation of the field of binocular fixation. It may therefore be laid down as a practical rule that the dislocation of the optical centre should be effected by displacing the whole lens, rim and all, as much as can be done without interfering with the field of binocular fixation,* leaving only the remainder (should any more be required) to be obtained by decentration proper, that is by decentering the lens *in* its rim.

* *i.e.* The range of lateral binocular vision.

To take an example, let us suppose it is desired to prescribe spectacles such that each optical centre is 10 mm. nearer to the middle line than the centre of the eye, and we have found by the localiser that the centre of each eye is 32 mm. from the median (sagittal) plane. The effect of limitation of the field of binocular fixation must be considered for each case, for its inconvenience or otherwise depends on the distance of the patient's occupation; but, say that on consideration, 5 mm. of *displacing* for each lens is all that is advisable; that will make each geometrical centre 27 mm. from the middle line, and leave 5 mm. for *decentering*.

In prescribing the spectacles, therefore, some such form as the following would be used.

	R.	L.
Spherical.	+ 4 D	+ 4 D
Cylindrical.		
Geometrical centre.	27 mm	27 mm.
Decentration.	5 mm. inwards.	5 mm. inwards.

To make such a pair of lenses the optician *might* first make two larger lenses of +4 dioptries, and 10 mm. (*i.e.* twice the decentration) wider than the lenses required, which would then be cut out peripherically as in *Fig. 23*. But this would involve a serious waste of time and labour, since precisely the same result may be attained by the simpler plan of finding from Table III. the prismatic equivalent of the decentering, and then proceeding as he is accustomed to do when ordered to combine a prism of that *deviating* power, with a lens. He would cut the prism required, and then impart to its surfaces the required sphericity. Lest any confusion should arise here between the deviating and refracting angles it will be well to repeat, that the angle of refraction by which the two surfaces of a prism are separated, and by which the workman first cuts a prism, is twice the angle of deviation which is given in the table, and marked on the prismeters. In the example we have taken, in which lenses of +4 D are decentred 5 mm., a reference to Table III. shews that the prismatic equivalent is $1^{\circ} 10'$,

but this being the deviating angle must be doubled to get the angle of refraction, which will therefore be $2^{\circ} 20'$. Two prisms, each with their plane surfaces at an angle of $2^{\circ} 20'$ will now be made, and a sphericity of $+4$ D be given to each surface. Having thus shaped the decentred lenses, the workman would next place them in a frame made with the centre of each rim 27 mm. from the middle of the bridge. The effect of such a pair of spectacles on a patient with the centre of each pupil 32 mm. distant from the middle line, would be the same as if normal lenses of $+4$ dioptries, each combined with a prism of $2^{\circ} 18'd$ were placed exactly in front of the two eyes; as may be easily seen from the table; for 5 mm. of *decentering* + 5 mm. (*i.e.* $32 - 27$) of *displacing*, give a total of 10 mm. for the alteration in position of the optical centre. Under the heading of 10 mm. in the table, opposite 4 D, is found the *combined* prismatic effect, viz. $2^{\circ} 18'$. With this, of course, the optician has nothing to do.

Though it was thought well in passing, to give an instance of how a decentred lens may be prescribed, a better plan will be to mention, not the decentering, but the prism equivalent to it. This will save the optician all calculation, with the attendant possibility of a mistake.

It will be a simple proceeding for the surgeon, after finding the total prismatic effect it is desirable to produce, to deduct from it the proportion to be attained by displacing and set down the rest in the form of a prism whose surfaces are to receive the needed sphericity. To take a varied illustration, we will suppose the lenses to be sphero-cylindrical. If the axis be vertical, the effect of a cylinder on convergence is precisely the same as that of a spherical lens of the same curvature, but with each departure from the vertical it acts like a weaker spherical lens till with axis horizontal its effect is *nil*. A lens, therefore, of + 3 D sph., + 2 D cyl. axis *vertical*, would affect convergence like a + 5 D sph. : with axis *horizontal* it would affect convergence like a + 3 D sph. Let us take for an example such lenses of + 3 D sph. and + 2 D

cyl., axis vertical, the total effect on convergence being that of a spherical lens of + 5 D. Suppose it is wished to relieve the convergence of each eye by 2° for an occupation distance of 15 inches. It is decided, let us suppose, that 7 mm. of displacing can be allowed without interfering with the required field of fixation. But 2 mm. out of these 7 mm. must be deducted as useless for the purpose, since they only go to counteract the *excess* of convergence, which lenses placed precisely in front of the centres of the eyes would occasion in near vision, for it is clear that the lines of fixation would then traverse the lenses internal to their optical centres. With habitual vision for 15 inches, we have to allow 2 mm. for this reason, and with vision for 10 inches we have to allow 3 mm. since only if the lenses were 2 mm. or 3 mm. respectively, internal to the centre of the eyes, would they have no effect on convergence, for then only the visual axes would traverse the optical centres. This position therefore forms the zero, by departing from which in either direction the convergence is affected. To return to our example, after deducting these

2 mm., 5 mm. of *effective* displacing remain. By Table III. we find the prismatic equivalent of 5 mm. of displacing to be exactly 2° . This is all we desired, and there is therefore no need for decentering. Had it been desired to afford greater relief to convergence, say 4° , then the remaining 2° should be prescribed as prismatic combination. If the centre of each eye be 32 mm. from the middle line, then this, less the total 7 mm. of displacing, would make the geometrical centre 25 mm. from the middle of the bridge, and it would stand thus :—

	R.	L.
Spherical.	+ 3 D.	+ 3 D
Cylindrical.	$\left\{ \begin{array}{l} + 2 \text{ D} \\ \text{axis vert.} \end{array} \right.$	$\left\{ \begin{array}{l} + 2 \text{ D} \\ \text{axis vert.} \end{array} \right.$
Geometrical centre.	25 mm.	25 mm.
Prismatic.	$\left\{ \begin{array}{l} 4^\circ (2^\circ \text{ d}) \\ \text{edge out.} \end{array} \right.$	$\left\{ \begin{array}{l} 4^\circ (2^\circ \text{ d}) \\ \text{edge out.} \end{array} \right.$

The optician should understand that the new marking is intended whenever the letter "d" is appended. In this case, therefore,

he would cut two prisms, each with an angle of refraction of 4° , and impart to one surface a sphericity of $+ 3$ D, and to the other a cylindricity of $+ 2$ D, setting them in a frame with the centre of each rim 25 mm. from the middle of the bridge.

To relieve convergence, prisms should be "edge out;" while convex lenses should be displaced inwards, and concave lenses outwards.

To meet excessive convergence, prisms should be "edge in;" convex lenses displaced outwards (only slightly practicable owing to limitation of near binocular fixation), and concave lenses inwards. It is with strong lenses, such as those for aphakia and high myopia, that care in the position of the lenses is of chief importance.

"Orthoscopic Spectacles" as described by Dr. Scheffler, have been so long known that they must not altogether escape mention. In these, accommodation and convergence are affected in equal amount. The two lenses have but one optical centre common to both, just as though they were cut from opposite edges of one large lens. The proof of their

correct manufacture is that they throw a *single* distinct image of a flame upon a wall. They have generally been prescribed in a few standard strengths, but they can be made for any patient by combining with each of his lenses a prism, whose deviating angle is found in Table III., opposite the description of lens, and under the number of millimetres by which the optical centre of each eye is distant from the middle line. These spectacles undoubtedly may have their place, but it is better to ascertain the conditions of convergence in each case and prescribe accordingly, rather than to adhere to any fixed combinations.

PART III.—LOCALISATION.

LOCALISING THE EYES.

IT will be at once evident from the preceding section, that it is impossible to prescribe spectacles of any kind with a view to produce a definite prismatic effect without first knowing the precise distance of the centre of each eye from the middle line, and in clinical work the need must have been often felt for a quick yet reliable objective test. Many subjective tests are in existence already for the purpose of telling, not the distance of *each* from the middle line, but the mutual distance between the centres of the two eyes, ("interocular" or "intercentral" distance); such as Smee's "visuometer" as used by Donders, Landolt's chiasmometer, Snellen's frame, or Dr. Johnstone's trial frame with the short tubes in the two discs. But an objective test is more desirable, and especially one for each eye, and though it is true that single points have already been placed before each pupil, such as, for example, the intersection of cross wires, with a

view to obtain this information, yet the very principle of such a *single* "sight" or "bearing" is fallacious. It affords no guide or guarantee for the position of the observing eye, which is therefore left to guess-work. For a test to be true in principle, not only must the visual lines of the observing and observed eye coincide, but the line so composed must be exactly at right angles to the line uniting the centres of the two eyes, or at least if one eye be examined with any angle of inclination, the inclination must be the same in the examination of the other.* It need hardly be said that this cannot be ensured when only a single point is used for a bearing. To overcome this difficulty the writer has had a little device made (*Fig. 25*), with two sights

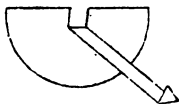


Fig. 25.

so disposed as to always be in a line at right angles to any trial-frame in which it is placed. One pupil is localised at a time, all that is

* On the principle of the parallelogram.

necessary being to increase or diminish the breadth of the frame till the two sights and the centre of the pupil are in line as in *Fig. 26*; the patient meanwhile is bidden to be



Fig. 26.

looking at the pupil of the surgeon's observing eye, by doing which the two visual lines (*i.e.*, that of the observing and that of the observed eye), come to practically coincide. If the patient is a child it is quite easy to excite its interest in its own miniature reflection in the surgeon's pupil while taking the observation, adeptness in which needs a few trials to become familiar with the parallax motion. The instrument is then placed in the other rim of the frame, and the observation repeated for the other eye.

By this method we comply with the two afore-named conditions of accuracy; the visual lines of the observing and observed

eyes coincide, and of necessity they are both at right angles to the trial-frame. The frame must of course be one movable by a screw, and marked in millimetres, so that the record can be read off after localising each pupil. The distance of the centre of each eye from the middle line is in each case *half* what is registered by the frame. It is true that the present methods are considered sufficiently exact for practical purposes, but there is, nevertheless, a pleasure in working on correct principles, and a number of small inaccuracies in the different steps of testing and prescribing may amount together to a considerable error. The frequent and careful use of this principle will shew how many an unsuspected difference exists in the position of the two eyes, and will train the surgeon who uses it to a quicker appreciation of asymmetry and its amount. When ordinary spectacles are prescribed for eyes placed unsymmetrically, the prismatic effect is greater for one than the other, which may (or may not) be deleterious, or even advantageous, according to the nature of each case which, therefore, needs individual investigation.

PART IV.

ANALYSIS OF SPECTACLES.

So far we have dealt with the synthetical part of our subject, how to combine lenses and (virtual) prisms. The analytical part must now be considered. When a patient comes to us with a pair of spectacles already in use, but which cause discomfort, how are we to analyse their prismatic effect, and find how the glasses are centred? One thing is clear, that we must set ourselves to discover with all possible accuracy the cause of the discomfort. It *may* be due to the irritability of the patient's nervous apparatus, but before deciding this we must exclude the other alternative, that the spectacles are not the best in every way that could be given. The focal length of the lenses is easily determined by the plans given on page 16. The next thing is to measure the distance between their optical centres, or, preferably, the distance of each from the centre of the bridge, and this may be done in several ways. If sunlight is procurable the

spectacles may be held at their focal distance from a card exactly parallel to the two lenses, then the distance between corresponding points of the two spots of light on the card gives the required distance between the optical centres. If artificial light be used, the distance between the spots of light (more strictly, between corresponding points in them), must be multiplied by the distance of the light from the spectacles, and divided by that of the light from the card. In this experiment care must be taken that the light and the bridge of the spectacles are in a line perpendicular to the lenses and the card. A modification of the Phakometer could easily be adapted for this purpose. But inconvenience attaches to the use of either direct sunlight or artificial light, and if they can be dispensed with the better. *Fig. 27* illustrates

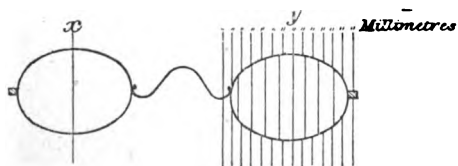


Fig. 27. A simple way of telling the distance between the optical centres of a pair of spectacles.

a rough mode of telling the distance between

the optical centres. The spectacles are held horizontally, and some inches above a card marked to one side with a vertical line x , and towards the other side with parallel lines y , at different measured distances from the single one. The observer, holding his left eye about a foot above, and as nearly vertically over the left lens as he can judge, closes the right eye, and moves the spectacle frame from side to side till the line x , appears unbroken by the left lens. Now, without moving the head, the right eye is opened and the left closed, and that line which appears to be least displaced by the right lens is the line nearest its optical centre, and the number above it furnishes a rough estimate of the required distance between the two optical centres. To ascertain whether each optical centre is midway between the upper and lower border of its rim, each lens must be held lengthwise over the left hand line till it appears to run continuously. The principle (though not new) of this test is so simple, yet its imperfections so many,* that I have

* Besides its want of accuracy, it only gives the mutual distance between the optical centres, and not the distance of each from the middle of the bridge, and it is not available when the optical centre lies outside the lens.

constructed an "Analyser" to secure the former, without the latter; it is shewn in *Fig. 28*. The two essential conditions are that the lenses should be parallel

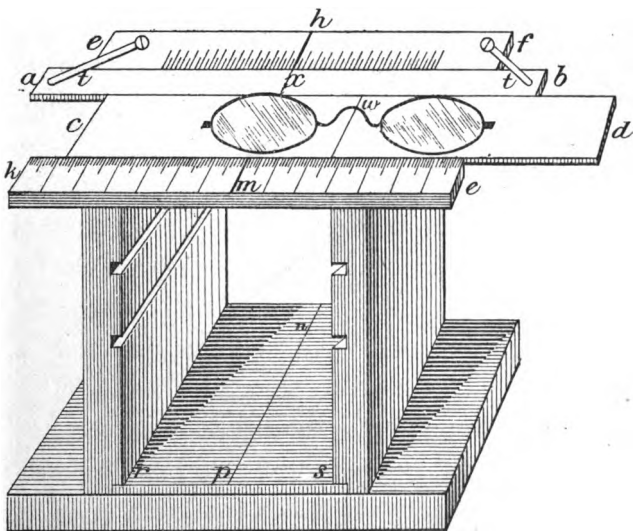


Fig. 28. The first form of analyser.

to the card, and that the line of vision in looking through each lens should be exactly vertical. The first is secured by laying the spectacles on the plate of glass *c d* which is movable from side to side; and the second by keeping the eye so that the line *x* is main-

tained in apparent coincidence with the line np . The letters $a\ b$ indicate the narrower strip, also movable, marked exactly across the middle, with a transverse line x . On either side of the slides is a millimetre scale with the zero in the centre. The broad slide has a long line w right across it opposite the zero of its scale. The card $r\ s$ has only one line upon it, exactly beneath the central lines of the glass strips, and it can be placed either in the bottom of the apparatus as in the figure, or in the grooves higher up, for lenses whose focal length is shorter than the height of the glass plates above the lowest grooves. The card is generally used in its lowest position, because distance of the line upon it from the lenses, as we have already seen with prisms, magnifies the phenomenon, and makes the experiment more delicate. The height of the upper surface of the glass plates from the card in the lowest grooves is about $4\frac{1}{2}$ inches.

To analyse a pair of spectacles, lay the centre of the bridge on the line w , and place the observing eye so that the lines x and np appear to coincide. Now move the broad

slide bearing the spectacles till the line $n\ p$ appears undeviating through one lens; then w points to the distance between the optical centre of that lens and the centre of the bridge. Repeat in the same way for the other lens.

The *geometrical* measurements, as for the breadth of frame and the rims, are made by laying the spectacles still lengthwise, but half on the broad slide and half on the narrow. By keeping the line x at zero, and placing any required point of the spectacles over it, then drawing out the line w to the other point, the latter line indicates the required distance, on the scale $k\ e$. It is well to have the narrow strip fixed by strong pieces of watch spring $t\ t$, like those for microscope slides, or by a little screw at one corner of the frame.

Lastly, by laying the geometrical centre of a lens opposite the zero of the scale $k\ e$, the line $n\ p$ will, if it be a decentered lens, appear displaced through it. How great is the apparent displacement? By answering this we tell the prismatic equivalent of the decentering without recourse to any table.

We must use another sight* fixed to the narrow slide perpendicularly beneath its line x , then by holding the eye so as to keep them both in apparent coincidence (thus ensuring a vertical line of vision) and moving them till they appear exactly abreast of the apparent displacement of the line $n\ p$ as seen through the lens, the prismatic equivalent of the decentering is indicated by the degree on the scale $e\ f$ to which x points. The special applicability of this mode is when the optical centre lies outside the lens. The principle would, of course, be the same if instead of moving the glass slide, the analyser were so made as to let the card at the foot be moved alongside a metric scale. When the lenses under test are of shorter focal distance than the height of the analyser, the card must be placed in one of the other two pairs of grooves : then, though the use of the scale $k\ e$ is unchanged, it must be remembered that when the card is in the grooves half way up, each figure in the scale $e\ f$ must be multiplied

* Another way is to use a plane mirror instead of the card $r\ s$ and keep the line x in line with its reflection—a little difficult sometimes.

by two, and when the card is in the highest grooves, as for cataract lenses, each must be multiplied by four.*

ANOTHER FORM OF ANALYSER.—The instrument already described is, perhaps, most appropriate for surgeons, since no artificial light is needed, and it is small and portable. For opticians, however, who use large numbers of spectacles and wish to classify them, another kind is recommended, which permits both the focal length and the position of the optical centres to be tested at one and the same time.

A plan of it is shewn in *Fig. 29*. Upon a horizontal strip of wood *k l*, is fixed an equatorial portion of a large lens (preferably plano-convex, as in *Fig. 31*, to lessen spherical

*For the guidance of opticians it may be said that the scale *e f* can be marked either in millimetres or in degrees; if the latter then the height of the lenses above the card must be 53·3 mm. or some multiple of that number, for the degrees to be one millimetre from each other, or some multiple of a millimetre. But if marked in millimetres the height of the lenses above the card should be 100 mm., so that by a table of tangents affixed to the analyser the degree can be found. This is the most exact method, especially for strongly prismatic lenses, but being rather less simple is not mentioned in the text.

aberration). *Fig. 30* represents in miniature how this rectangular piece is cut from the

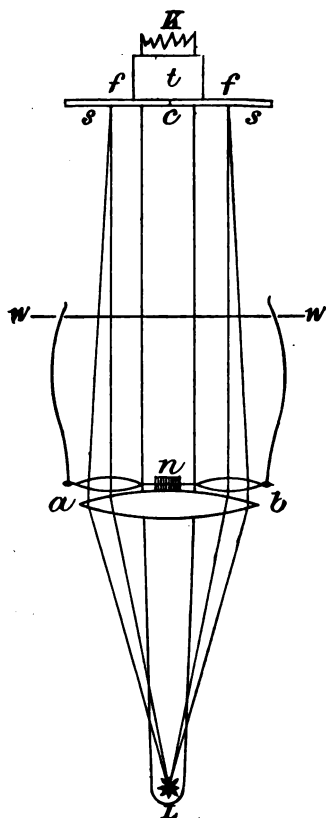


Fig. 29.—Second kind of Analyser.

equatorial band or zone of the large lens: it should be as long as the broadest spectacles



Fig. 30.—A lens, with the equatorial zone marked by dotted lines.

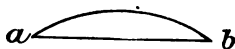


Fig. 31.—Plano-convex lens.



Fig. 32.—An Analyser made with a trial-frame.

used. At its focal distance is placed a flame L , so that parallel rays of light are thrown upon a screen $s s$, which is fixed to the traveller t , and is provided with a metric scale, running right and left from the central zero at c . A small wooden nose n is provided to support the bridge of the spectacles, and two wires $w w$, fixed to the under surface of the strip of wood, so as not to interfere with the movements of the traveller, support its limbs or temple-pieces. Two movable stenopæic slits, (in default of which, the large lens should be blackened except in two vertical stripes,) greatly increase the definition of the focal points $f f$, which indicate upon the metric scale the distance of each optical centre from the middle of the bridge. After laying a pair of spectacles in position, the traveller is moved till distinct images are thrown on the screen; then the dioptric strength or focal length is read off from the flat strip which is marked both in dioptries and inches, and the position of the optical centres is read off from the screen. *Fig. 32* is to shew how a temporary style of the instrument can be made by placing in each

side of a common adjustable trial-frame a lens in conjunction with a prism.* But rectangular reading glasses can often be obtained in shops, and the portions not to be used can be covered with asphalt or with black silk plaister.

THE EFFECT ON CONVERGENCE OF DISPLACED OR DECENTRED LENSES.

This study will cause embarrassment if allowed in any way to be confused with those of previous pages, and, perhaps, for that reason, the less said on it the better. It must be clearly borne in mind that the prismatic equivalent of decentering a lens, and the effect of that decentred lens on convergence.

* The lenses chosen should have a focal length equal to the most convenient distance of the flame, then by Table II., prisms should be selected nearest to the strength indicated opposite the dioptric description of the lens in or near the columns headed by 28 mm. or 30 mm. After setting them in position with the apices of the prisms exactly outwards the final correction is made by adding to each couple a vertical stenopæic slit, and holding the whole combination exactly athwart direct sunlight, so as to throw two fine images upon a card held at the focal distance of the lenses. The trial-frame is then adjusted so that the two images exactly coincide. Their action now is the same as that of the large lens.

are two distinct things, though at first sight they appear the same. Suppose we decentre a lens, or what is the same thing, suppose we place a normally centred lens precisely before one eye and associate a prism with it. We might anticipate that the angle of deviation of this prism would exactly express the effect on convergence. But it is not so. *Fig. 33,*

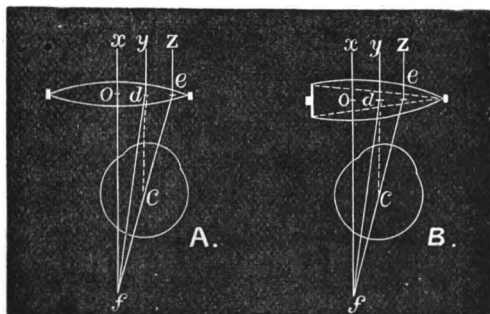


Fig. 33.—A. The right eye is looking at a distant object through a lens *displaced inwards, rim and all*, by a distance $o d$; $d c e$ is the effect on convergence. B is the same eye looking through a lens of the same focal length, but *decentred in its rim* by the same distance $o d$. The dotted lines indicate the prism that would be equivalent to the decentring, and the effect on convergence is the same as with A.

B, represents a decentered lens, the action of which is precisely similar to a prism and lens, for, as said before, it is as if the lens were split in two, and the prism shewn in dotted outline were inserted between the two halves.

Now it will be evident at a glance, that the angle $c d f$ is the deviating angle of the virtual prism, while the greater angle, $d c e$ is that which represents the effect on convergence. It makes no difference to the effect on convergence whether a lens is decentred, or displaced to the same amount as in *Fig. A*.

There is one exception to the discrepancy between the prismatic equivalent and the effect on convergence, and that is when the lenses are *convex* and the object of fixation is at their focal length. Within that distance the effect on convergence is less, and beyond it more, than the prismatic equivalent. But with *concave* lenses it is always *less*.

PART V.
A BRIEF OUTLINE OF THE
CHIEF CLINICAL APPLICATIONS
OF PRISMS.

THERE are seven uses of prisms in the consulting room which may be described first ; then five more uses as worn by patients will follow, making in all twelve clinical applications.* Prisms are—

A.—OF SERVICE IN THE CONSULTING
ROOM.

1.—To measure *the absolute minimum of convergence* (r^c). This is generally a negative quantity, and then the minimum of convergence of the visual axes is identical with their maximum of divergence. Its measure is therefore taken by finding the strongest pair of prisms, with their edge outwards, compatible with single vision of some distant object, as

* In working with prisms, we are happily not concerned with the angle alpha, either in testing or prescribing.

shewn in *Fig. 34*. The *deviating* angle of



Fig. 34.—The absolute minimum of convergence.

each prism expresses the “absolute minimum of convergence” for each eye. The figure also makes clear that the visual axes meet behind the head during the experiment, and their point of intersection is still called “the far point of convergence,” though its position is negative instead of positive. If a *single* prism be used, since its effect is distributed between the two eyes, its angle of deviation must be mentally halved for each. Remoteness of the point of fixation during the experiment is an important consideration if it is desired to reach the *absolute* minimum, for the knowledge of the object being at a great distance favours the evolution of diverging energy, and in normal eyes the sympathy of convergence with the very beginnings of accommodation (even for instance for six metres) is very great.* If

* Investigations, &c., Maddox, “*Jour. Anal. & Phys.*,” Vol. XX., p. 574.

lenses are worn in the trial frame, for ametropia, of sufficient strength, the experiment can be made by separating them if concave, or approximating them if convex, till double vision occurs, and then the prismatic effect can be calculated from Table III.

Thus, if the distance between the optical centres of lenses of -4 D be increased till it is 16 mm. greater than the distance between the centres of motion of the eyes, we divide the 16 mm. between the two eyes, for clearly each lens is displaced 8 mm., and therefore by the table there is $1^{\circ}50'$ of divergence for each eye, or just one metre angle. It is expressed by saying that the absolute minimum of convergence is $-1^{\circ}50'$. Dr. Stevens finds that with vision for six metres, the normal power of the abducting muscles is measured by a prism of 8° , or, possibly, 9° . He first corrects any existing ametropia, but does not appear to calculate for the prismatic effect of the lenses during the experiment.—(Archives of Oph., June, 1888, p. 163.) Schweigger also gives 8° as the average strength of prism in *E.*, and quotes Schuurman as giving 5.6° as the average prism in *H.*, and

11.6° in *M*. In making this test with *M*, refraction should first be corrected, and the effect of the lenses on the direction of the visual lines calculated for by Table III. In *H.*, the test should be made both with and without lenses.

2.—To measure the *absolute maximum of convergence* (p^c). Find the strongest adducting prisms, as in *Fig. 35*, compatible with

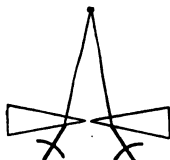


Fig. 35.—The absolute maximum of convergence.

single vision of a test type or printed page held as close to the eyes as accommodation will permit.

This test, though described for completeness, is not easily enough made with ordinary prisms to be much used, or to replace in practice the old established custom of advancing a finger towards the root of the nose till one eye deviates outwards, or the use of Dr. Landolt's Dynamometer in which the finger is replaced by a line of light. The two last tests,

however, it may be suggested, do not give the “*absolute* maximum of convergence,” for as soon as the point of fixation passes within the binocular near point of accommodation, diffusion circles appear on the retinae, and increase rapidly in size with every approach till the eyes resign the impossible task of accommodation—then the ciliary muscle relaxes, and with it the convergence.

Just as in absolute hypermetropia, efforts of accommodation cease as soon as the impossibility of obtaining sufficient definition is realised. These tests discover only, I believe, the point of *the resignation of ciliary effort*. Even were the accommodative efforts to persist, it is scarcely to be expected that two pictures on their respective retinae, each composed of a mass of diffusion circles, should excite the desire for fusion in its full strength, as clearly defined pictures would. At first sight the highest adducting prisms compatible with single vision of a test type held at the absolute near point of accommodation *would* seem to give the true “absolute maximum” of convergence; but here there is a new difficulty, for the chromatic disper-

sion of the prisms spoils the definition of the pictures on the retinae, though truly it might be avoided by using a monochromatic light.* By adding the result of this test to the already ascertained "negative convergence," we get the "absolute range (amplitude) of convergence" (a^c), of which, according to Dr. Landolt, not more than one third or one fourth can be continuously in exercise for comfortable vision.

3.—To measure the "*relative range of convergence*" (a_i^c). For this we find the strongest pair of abducting prisms, as shewn

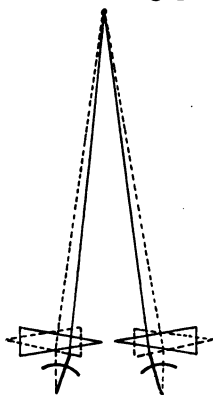


Fig. 36.—The relative range of convergence.

* Such light may be obtained of a pure yellow by placing common salt, or of a pure red by placing some salt of strontium, upon the wick of a spirit lamp of which the flame is kept steady by incombustible gauze.

in dotted outline in *Fig. 36*, and then the strongest pair of adducting prisms, as shewn in continuous outline, compatible with single distinct vision of an object or type at some chosen distance. The distance most suitable is that at which the patient's daily work is done (occupation distance), and for which spectacles are most required.

The abducting prisms measure the negative part of the range (r_1^c), and the adducting prisms its positive part (p_1^c). This test would probably be the most valuable of any, if the best ratio between the negative and positive parts were well worked out for different distances of vision; meanwhile it may be gathered in large part from *Fig. 57* of Donders' "Anomalies, etc." At twelve inches, for instance, the subject of his experiments had a relative range of nearly seven metre angles, the negative and positive parts being equal. At eight inches the relative range is slightly greater, but its parts are still equal. At six inches the positive part exceeds the negative. For distances greater than twelve inches the chart is incomplete on the negative side, but the positive

part is at 24 inches, 3 full metre angles, and at 72 inches about $2\frac{1}{2}$ metre angles.

Since the relations between convergence and accommodation become temporarily altered by prolonged efforts to overcome strong prisms, all observations should be taken as quickly as possible; hence the rectangular trial-frame of *Fig. 20* would be better than an ordinary one, since no time is wasted in setting a prism.

The principle of "rotating prisms," as introduced in America some years ago, should be a valuable one;* but as I have not yet tried them, more cannot be said now.

In testing the ranges of convergence it is undoubtedly best to use *pairs* instead of single prisms; then the deviating angle of each gives the result for each eye. Should, however, a single prism be used, its deviating angle must be halved for each eye; and should the pair be an odd one, that is, with one prism stronger than the other, half the sum of their deviating angles must be taken for each eye. The prismatic relief found

* These prisms are coggled edge to edge so as to rotate, one before each eye, in opposite directions at equal rates.

desirable to give by any of these plans would of course apply to each lens in the spectacle frame.

4.—To *dissociate convergence and accommodation*. This is done by placing a weak prism with its edge upwards or downwards before one eye. One of 4° (2° d) is generally strong enough to create vertical diplopia which cannot be overcome in distant vision ; but for near vision, a stronger prism must be used. Graefe's was 15° .

In this way the stimulus to convergence is suppressed, and the eyes take that position, relatively to each other, which is due to the central association (in the nerve centres) between convergence and accommodation. Accommodation is in normal exercise and creates a definite proportion of associated or sympathetic convergence, which it is the purpose of the test to estimate. To give a simple illustration, we may compare the centres for convergence and accommodation to the two legs of a tuning fork ; the slightest vibration in one provokes vibration in the other. It is a perfect instance of irradiation, which appears to be a necessary accompani-

ment of all nerve-cell energy, but which is here economically gathered into a mutual channel between two confederate functions which are always associated in daily work. If the two images in this test appear in the same vertical line, the associated convergence is just equal to the accommodation ; if they are not in the same vertical line the diplopia is of course either homonymous or heteronymous. In the former case convergence is in excess of accommodation, and we say there is "relative convergence" ; and in the latter there is a deficit of convergence, and we say there is "relative divergence."*

* By an easy paper experiment communicated to the "Roy. Soc., Ed." (Proc. 1883-4, p. 433), for the author by Prof. Crum Brown, any one may convince himself that with dissociated distant vision some convergence of the visual axes is generally, though not always present. This was called "the initial convergence." With accommodation for nearer distances, "associated or accommodative convergence" is added to it till the "point of coincidence," where accommodation and convergence are abreast. For distances nearer than this there is generally relative divergence, which, after gradually reaching its maximum, again declines to a second point of coincidence near the near point of accommodation, and speedily gives way towards the absolute near point to relative convergence. These and kindred points will be found worked out in the "Jour. of Anat. and Phys.," vols. xx. and xxi, in papers already referred to. The results

The point of fixation may be, according to Von Graefe's suggestions, either a distant flame, or a vertical line with a dot situated upon it on a card. In the latter a fallacy has been shewn, from the fact that the reduplicated line still creates a desire for single vision of those portions which overlap.* When a light is made the point of fixation, a double prism, like that in *Fig. 37*, makes it much easier to detect the condition present

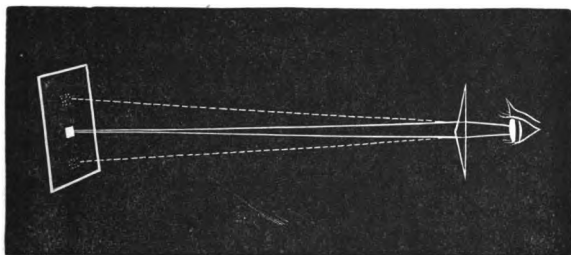


Fig. 37.—A double prism. From "Jour. Anat. & Phys.," Vol. XX., p. 496.

by observing whether the central image, which is seen by the unclad eye, appears to

were obtained by the "visual camera"; and to obtain similar ones it is essential to employ a method of the same kind which takes note of the tiniest aberrations, and allows them full time to occur in a field entirely dark but for the two points of light.

* Noyes, "Treatise on Diseases of the Eye," New York, 1882, p. 88.

the right or left of the imaginary line between the other two, which are false images seen through the prism. The degree of deviation can be measured by finding the additional prism, edge in or out, required to bring the images into a vertical line, as suggested by Graefe; or the first prism may be rotated till the images are vertical, and then from the strength of the prism and the degree of turning, a calculation can be made of the deviation.*

For near vision the double prism may also be used, as in the figure, or with a device marked on a card, which measures the deviation at the same time; but I have come to prefer a single prism, mounted with its edge upwards on one end of a strip of wood along which a

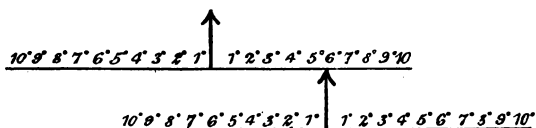


Fig. 38.—A metric device for a single prism. The lower row is marked on a card, and the upper is its false image.

* The sine of the angle through which the false image was displaced, is the multiple of the sines of the angle through which the prism has been rotated, and the angle by which it deflects rays of light. $\sin. x = \sin. \Delta \sin. r.$

traveller bears the same device, which now appears only doubled as in *Fig. 38* instead of trebled. It is of course desirable to make this test at the occupation distance of different patients, and if the scales are marked in degrees or metre angles a different one is necessary for each distance ; if marked in mm., and provided with an indicator capable of being lengthened or shortened, one is sufficient, but a calculation is necessary.

What is the due significance to attach to this test? It clearly does not decide the strength of one rectus, for convergence is a single function affecting both eyes equally. It is true that each rectus is a link in the chain of convergence, and *may* be the weak link, but that would shew itself best in testing the lateral movements of the eyes. Neither does it afford a pure test of the strength of convergence ; for the converging innervation might respond in power to its *proper* stimulus and yet fall short of this test from its central communication with accommodation being abnormal or affected by disease. Neither does it entirely test the freedom of communication between the centres ; for that might

be perfect, and yet the test exhibit failure from some imperfect link in the chain of convergence. It really tests all in a joint way, so that its full value only comes out when it is made for both near and distant vision, and is conjoined with some of the previous tests to interpret the exact import of its revelations: the way in which these vary slightly according to the time of day, the state of the sympathetic system, and other conditions, has been described elsewhere.*

5.—To disclose any *tendency to vertical diplopia* (hyperphoria). Accommodation and convergence are dissociated for this purpose by a prism with its edge *outwards*, and slightly stronger than can be overcome—say one of 6°d. In this test especially, precision in the setting of the prism is essential, since imperfect setting can produce in a normal patient an apparent difference in the height of the two images. This is shewn in *Fig. 13*.

Interesting cases of latent vertical diplopia, with very successful correction, have been recorded by many, especially in America.

* "Investigations," &c., J. A. P., vol. xx., p. 568.

In making the test, the object should be a flame at the distance of 6 metres, and the full prismatic correction should then be given.

Instead of a single prism, a double prism with its axis horizontal, like that in *Fig. 37*, may be used, and it is not difficult for the patient to tell whether the central of the three images is equi-distant between the other two. Better still is a stronger double prism with each refracting angle of 10° : this is used with its axis vertical instead of horizontal so that the three images appear in one horizontal line, and the patient is asked to say whether the central one is higher or lower than the line between the other two.

Yet a fourth, and perhaps easiest way of making the test is to use an ordinary stereoscope,* marked before one eye with a vertical line graduated in degrees up and down from a central zero point, and before the other eye with a horizontal line exactly level with the zero point just mentioned. On looking into the instrument, the horizontal line appears to

* "Ophthalmic Review," An Abstract, &c., Dec. 1886, p. 348.

lie across the vertical one ; if it crosses it at zero there is shewn to be no tendency to vertical diplopia ; but if otherwise, the latter is present, and its amount is expressed by the figure which the horizontal line crosses, and which the patient is asked to read off. The stereoscope must be held horizontally and with care.

All these are "diplopia tests," or "equilibrium tests," since they depend on the dissociation of the eyes by the artificial creation of diplopia. But Stevens has shewn the desirability in these cases of also finding the highest prism, edge up, compatible with single vision, and the highest prism, edge down.*

6.—Prisms have sometimes been used to measure strabismus, or to measure the degree of any existing diplopia, but for this they are useless.

Not so, however, when the purpose is to ascertain *by what proportion diplopia must be lessened* to place its entire correction just within the control of the innervation con-

* "Archives d'Ophthalmologie," XVI ; 6 ; p. 544.

cerned in the preservation of single vision. It suffices to find the weakest prism, with its base-apex line parallel to the line between the two images, which enables single vision to be effected. The deviating angle of this prism informs us of the proportion of the diplopia which is *beyond* control, and when this proportion is deducted from the whole diplopia, the remainder is the proportion which can be brought *under* control. It is sometimes advisable to prescribe prisms just strong enough to bring the diplopia well under the control of "the fusion innervation" (as it is sometimes named) but no stronger, so as to exercise the neuro-motor mechanism till its strength is regained. Compare p. 41. For homonymous diplopia the edge of the prisms must be directed inwards, and for heteronymous (crossed) diplopia, outwards, or, in simpler words, "place its apex in the same direction as that in which the eye deviates ; thus, if the eye turns outwards, the apex of the prism must be turned outwards ; if the eye turns in, the apex must be inwards also."—(Juler).

7.—To decide *the presence of binocular*

vision. The fact that a prism before an eye deflects the line of fixation has been turned to account by Graefe, in cases of suspected malingering, to see whether an eye *has such a thing* as a line of fixation, or in other words whether it is a seeing eye. The following is perhaps the fullest plan. After fixing the patient's attention, we may first place a strong prism, say of 30° , (edge in or out) before the *sound* eye. If, while doing this, the other betray no associated movement, vision is almost certainly binocular, for nothing but fixation could preserve it from accompanying the deflection of its fellow, except in paralytic cases. Should it move, however, nothing is proved beyond the expected fact that its fixation power is less perfect than that of the other.

The same prism is now similarly placed before the *doubtful* eye; if while doing so the other display an associated movement, vision is not only binocular, but the impugned eye is the best of the two, at least for the distance of vision employed at the time: but if there be no associated movement nothing is proved.

Lastly, on placing a prism of about 10°

before the doubtful eye, and *quickly* withdrawing the prism, we closely watch the eye from which it is taken ; for a corrective movement, if detected, at once tells us that its line of fixation has been deflected by the prism, and that it *has* therefore a line of fixation and is a seeing eye.

The subjective test, in which the patient's statements have to be relied on, is, for obvious reasons, often unsatisfactory, though it possesses the peculiar advantage of convincing a by-stander from the patient's own mouth, and of thus relieving the surgeon from the sole responsibility. It consists in placing a prism first before the unsound eye, and asking whether any object, preferably a flame, appears double. The reply is almost certainly negative. The prism is next placed before the sound eye, and the question repeated, "Do you now?" If incautious, the patient may admit that though he sees nothing with the bad eye, he sees double when the prism is held before the good one. A refinement has been introduced in America by first placing the edge of the prism partly over the pupil of the sound eye, to shew the

patient that vision may be double with that eye alone, when the other is covered by the hand. A stereoscope, however, with a circle on one side, and a cross on the other ; or Snellen's coloured test-types, afford better subjective tests than any with prisms.

B.—PRISMS MAY BE WORN IN SPECTACLES.

1.—To relieve any *strain between convergence and accommodation* (esophoria or exophoria). The existence and nature of the strain must, if possible, be first made out. An ideal investigation would include, after the usual study of accommodation : (1,) The total range and region of convergence ; (2,) Its relative range, with vision for occupation distance ; (3,) The effect of dissociating the two functions with both near and distant vision. But with present methods, to attempt all these makes too great a demand on time, except for a few cases in order to form a groundwork for others ; and in general, those tests must be selected which are most suitable for the case. How, when refraction also needs correction, to apportion the desired relief

between displacing on the one hand, and decentering or the addition of a prism on the other, has been shewn in the previous section on "Decentering of lenses." There is little to be gained from prisms stronger than 2° d.

Dr. Noyes' plan is to "first decide the proper working distance, and the correcting glass which for this point is required, and with it ascertain the muscular error," by dissociation, &c. He adds, "To give prisms equal to one half the amount of error is usually sufficient," and says, further, "We must sometimes order prisms for permanent wear, either with or without a refractive correction, and this is indicated when a muscular error has been detected in testing for the distance of 20 ft. Here the correction of weakness of the externi, or of vertical diplopia, is of the utmost importance, and the full correction must be prescribed. . . . It is sometimes extraordinarily gratifying to see what relief is obtained by suitably-chosen glasses." What he terms "insufficiency of externi for distance, and of interni for near vision," implies, he says, general muscular

weakness, and indicates constitutional treatment, and Dr. Dyer's "invigorant plan." This consists in giving the patient four squared prisms, of about $2\frac{1}{2}^{\circ}$, 5° , 10° , and 15° respectively: twice a day for ten minutes he is to fix a flame or door-knob at 20 ft., and exercise abduction and adduction (really relative divergence and convergence), beginning with the weakest prism, and mounting the ladder to the strongest. Dr. Noyes' following remarks are so apposite that we conclude this subject with them: "The true purpose of prisms for constant wear, or for working, is found in those cases in which the difficulty lies in want of balance between opposing groups by which one set predominates too much over the other, not in those cases where the muscular power as a whole is below standard. Weakness of all the muscles is seen in that tremor or jerkiness which the eyeballs show when fixed in some extreme position, or in the sudden jump which the globe makes on reaching a certain point, as the eyes follow the finger slowly from one side to the other. The jump comes when another combination of muscles is required by the

change of fixation, and means that all do not conspire to an equable and smooth action."— (Noyes, *op. cit.*, p. 94.)

2.—To relieve any *tendency to vertical diplopia* (hyperphoria). The existence and amount of the latent diplopia may be determined by one of the methods on p. 88. Then a prism whose deviating angle equals, or nearly equals, the angle of diplopia may be ordered. Since the degree is generally small, it is not often worth while to distribute the correction between two prisms. If the image seen by the right eye appears highest, a prism should be worn before that eye with its edge downwards, just strong enough to bring the highest image to a level with the other ; or the same prism with its edge upwards before the left eye would amount to the same thing.

Oblique tendencies (hyperesophoria and hyperexophoria) are best resolved into their component horizontal and vertical elements, to allow the first to be studied in connection with convergence, and the second to be studied independently ; but instead of prescribing separately the required horizontal and vertical prisms, a single prism is to be

ordered of such a strength and so intermediate in the direction of its apex as to have their combined effect. For formulæ, see p. 112.

3.—To *correct persistent and incurable diplopia*, if of sufficiently small degree. This is done by letting the patient wear a prism whose angle of deviation is equal to the angle of the diplopia, and whose edge is in a direction contrary to the displacement of that false image which is seen by the eye before which it is worn.

4.—To train the neuro-motor fusion-apparatus to *overcome by degrees a curable diplopia*, as in paralytic strabismus, or diphtheritic, or other pareses. Thus Donders wrote, "We may further, in paresis of a muscle, so far meet the disease by means of a prism, that in order to make the double images which have been brought near one another run together, the muscles will become powerfully tense which, for the alleviation of the paresis, appears to be no matter of indifference".* If one rectus alone be paralysed, the prism should be worn before the eye of

* "Anomalies," &c., p. 134.

that side, but if a conjugate innervation be affected, each eye should be supplied with a prism. In either case their strength should be such as to relieve that proportion of the diplopia which is beyond the control of the fusion function, but not strong enough to let the whole diplopia be overcome without a slight and harmless effort. At regular intervals the diplopia should be measured, to note its gradual decrease, and to order weaker prisms accordingly, which will still stimulate the paretic structures, till they regain control of the diplopia altogether, without the further need of prisms.

An undoubted difficulty in this treatment consists in the variations of the relative positions of the images in the different parts of the field of fixation. Schweigger seems to go a little too far in saying, "The correction of diplopia by prisms is indicated only when there exists secondary contraction of the antagonistic muscle, and, as a consequence of that, diplopia throughout the entire field of vision," and "the prisms should be chosen of such a strength as to correct only that part of the diplopia which

is due to this contraction of the antagonist." —("Handbook of Ophthalmology," trans. by Farley, 1878.) See the Appendix, p. 110.

5.—To *relieve convergence for near work in some cases of short sight*, where it is impracticable to remove the occupation distance, by concave lenses alone, far enough to avoid excessive converging effort. But this application of prisms is very limited, owing to the weight, to the illusory properties, and to the chromatic aberration of the prismatic combinations. Any tendency to divergent strabismus would be aggravated by this method, and even without that tendency being noted, such spectacles should be very carefully guarded from any attempt to employ them in distant vision, even if necessary by surrounding the desk or other scene of work by a light screen at such a distance that the visual axes can never become divergent. For the same reason distant vision spectacles should have their optical centres no further apart than the centres of rotation of the eyes; otherwise they cause actual divergence of the axes, the muscular strain of which is perhaps as detrimental to the coats of the eyes as that

of excessive convergence. I have seen a myopic patient, in whom spectacles prescribed by one of universally recognised skill caused discomfort for years, and were then improved upon by a pair selected at random by himself from a common store ; no doubt the refraction was perfect, but the optician had received no intimation of the position of the lenses, and for myopic *children* especially, spectacles are very apt to be too wide. In some patients, the movements of the elongated eyeballs are so hampered, that convergent strabismus appears in distant vision, and divergent strabismus in near vision. In such cases, if the two kinds of strabismus are not too extensive, the distant vision spectacles may well have their lenses decentred (not displaced) outwards, and those for near vision be displaced (and, if necessary, decentred also) inwards. Displacing is, for distant vision, less advantageous than decentering, since it interferes with the binocular field of fixation which it is here important to preserve. Schweigger says of prismatic spectacles for the muscular asthenopia of myopia that " They may be used with special advantage

when it is possible to employ a working distance of at least 10 or 12 inches."—(*Op. cit.*, p. 172.)

There are other applications of prisms, such as to wear a pair with their edges inwards to enable hypermetropes to accommodate more easily (a sure way to develop convergent strabismus), and Culbertson's Prisoptometer, in which a double prism is used to reveal anomalies of refraction, but they need not detain us. Another interesting use of prisms is to make manifest the presence of what Dr. Stevens calls "habitual unconscious diplopia." The suppressed picture of a flame, as has been long known, becomes often manifest on placing a weak prism before the eye, even though it be in the direction of correcting the diplopia. In other directions, however, it *might* be acting by creating diplopia. Lastly, it may again be mentioned that prisms should never be prescribed without a fair preliminary trial.

APPENDIX.

TILL attention was kindly called to it by Mr. Charles Wray, F.R.C.S., I was not acquainted with the work of Dr. Stevens of New York, whose thoughtful papers in the "Archives d'Ophthalmologie" (vi. 6), and the "Archives of Ophthalmology" (vols. xvi. and xvii.), well repay perusal. They deal with the subject of faulty tendencies of the ocular muscles, not so much from the optical standpoint, as with a view to afford surgical relief by a modified form of tenotomy. He has introduced a new nomenclature, as follows :—

I.—GENERIC TERMS.

Orthophoria.—Tendency of the visual lines to parallelism.

Heterophoria.—Tendency of these lines in some other direction.

II.—SPECIFIC TERMS.

Heterophoria can be divided into—

I.—*Esophoria*.—Tendency of the visual lines inward.

2.—*Exophoria*.—Tendency of the lines outward.

3.—*Hyperphoria* (*right* or *left*).—Tendency of the right or left visual line to place itself in a direction above that of the opposite side.

“This term does not imply that the line alluded to is too high, but only higher than the other, without indicating which of the two is defective.”

III.—COMPOUND TERMS.

Tendencies in oblique directions can be expressed in the following manner :—

1.—*Hyperesophoria*.—Tendency upward and inward.

2.—*Hyperexophoria*.—Tendency upward and outward. The designations *right* and *left* must be added to these terms. He says, “In registering the respective elements of these compound expressions, I employ the sign L. For example, if we wish to indicate that the right visual line tends above its partner by 3° , and that it has a tendency inward of 4° , these facts are inscribed as follows : Right hyperesophoria : 3° L 4° .”—

(" Archives d'Ophthalmologie," vi. 6, p. 542.) The *tendencies* of the visual lines thus classified must not be confused with actual *deviations*, as in strabismus. In strabismus, to which he gives the name of *heterotropia* (τροπος, a turning), there is habitual (conscious or unconscious) diplopia, but in *heterophoria* (φορος, a tending,) the visual lines only *tend* to deviate, and are restrained from doing so by extraordinary fusion effort, so that binocular vision is habitually maintained, but at the expense, often, of headaches and other nervous symptoms. These faulty tendencies are, in short, what have long been known as "dynamic (or potential) squint," (Von Graefe), or "latent squint" (Alfred Graefe).

Dr. Stevens retains the old expressions abduction and adduction in their usual sense, as representing the diverging and converging action of an eye, by which it overcomes a prism with its edge out and in respectively, and contributes the new term "sursumduction" for the overcoming of a prism with its edge up or down, and says, "It often happens that the images can be united when a prism is placed before an eye with its base up or down,

but that diplopia occurs if the prism is inverted, or if it is placed in its first position before the other eye." The standard distance at which he makes his tests is 20 feet, with the head in the primary position, and any error of refraction corrected, though it does not appear whether the effect of the lenses is accounted for. He says, "The usual power of the abducting muscles in orthophoria is measured by a prism of about 8° , or, possibly, 9° ," and of the adducting muscles by one of 50° , while the powers of sursumduction are normally measured by a prism of 3° . In manifest strabismus, diplopia is generally difficult to demonstrate, owing to habitual suppression of one of the images, but a red glass before one eye, or a weak prism, may make it evident.

Dr. Stevens believes that hyperphoria rarely exceeds 4° , and if any case appears an exception to this, hypertropia is to be suspected, and the suspicion is made almost a certainty if combined with it there is a lateral deviation of more than 6° . Esophoria of more than 10° , or exophoria of more than 8° is not likely to be found with maintenance of

binocular vision. ("Archives of Ophth.," June, 1888, p. 163.) His experiments are made with an apparatus called a "Phorometer." It consists of a vertical standard, supported by a tripod, and adjustable for differences of stature. It bears a hinged arm, which may be horizontal, or be used at any inclination notified by a scale of degrees, or it may be folded down altogether. At the hinged extremity it is provided with a spirit level, and in a groove along its upper surface, carriers bearing prisms can either slide or be removed at will. Instead of simple rectangular prisms, two discs can be used, each consisting of six prisms united at their apices, so that on rotation, prisms of increasing strength come before the two visual apertures. A tablet, marked with a small cross on one side, and a larger one on the other, is held by a rod at the distance of half a metre from the prisms, or at any other desirable distance. He first places the patient in the primary position, 6 metres distant from a flame, with the ocular muscles relaxed, and any refractive anomaly corrected; and then tests for hyperphoria by a prism, edge out, stronger than

can be overcome. If the two images are at different heights, hyperphoria is demonstrated and is measured by that prism which, with edge up or down, brings them to the same level. He next tests for esophoria or exophoria by a prism, edge up or down, too strong to be overcome, and measures the amount of deviation by the prism which, with edge in or out, makes the images vertical. Eyes, therefore, are characterised as eso- or exophoric, etc., when they are shewn to be so by tests made at the standard distance of 20 feet, and for the results of near-vision tests, Dr. Stevens proposes to speak of "exophoria *in accommodation*," etc., but this is scarcely precise enough, and it will be better to mention the exact distance of the test, and speak of exophoria at 20 feet, esophoria at 10 inches, and so on.

I have drawn up the following series of prismatic tests, for cases of suspected nerve trouble from heterophoria.

A.—WITH FLAME AT 20 FEET.

1.—With prism of 10° , edge out, or a stereoscope, test for hyperphoria (p. 88).

2.—With prism of 4° , edge up, test for esophoria or exophoria (p. 83).

3.—Find highest prism, edge out, compatible with single vision (p. 75).

4.—Find highest prism, edge in, compatible with single vision. (Rarely necessary.) (p. 106).

5.—Find highest prism, edge upwards, compatible with single vision (pp. 105, 106).

6.—Find highest prism, edge downwards, before the same eye, compatible with single vision (pp. 105, 106).

B.—WITH FIXATION FOR "OCCUPATION
DISTANCE."

1.—Find highest pair of prisms, edge out, compatible with single vision (p. 80).

2.—Find highest pair of prisms, edge in, compatible with single vision (p. 81).

3.—With a prism of 10° , edge up, test for esophoria or exophoria at working distance, using a device to measure the amount, as in Fig. 38 (p. 86).

C.—WITH FIXATION FOR THE ABSOLUTE NEAR
POINT OF ACCOMMODATION.

Find the highest prisms, edge in, compa-

tible with single vision of test-types, or use Landolt's dynamometer (p. 78). (The usual "finger test," the "cover test," the lateral movements of the eyes, and the distance of each eye from the middle line, are observations which should not be omitted.)

As to prescribing prisms for recent paralytic strabismus, Dr. Noyes puts the matter well in the following quotation: "Double vision which concerns fixation 10° above, and for all the field below the horizontal meridian, or which concerns the median region of fixation, is the most distressing, and calls loudly for aid. The office of prisms is usually confined to these regions, namely, on the median line, or for parts on or below the horizon. In fact, to extend their influence over the whole field is impossible, because the relations of the double images become entirely different in its different parts, and it is impracticable to adapt the prisms to these changes."—(*Op. cit.*) Dr. Stevens makes an important observation to the effect that slight vertical tendencies (hyperphoria) may modify the adducting or abducting power considerably, and mentions cases in which marked esophoria in distant

vision, and exophoria, or even diplopia, in near vision, disappeared after some co-existing hyperphoria had been remedied by a slight tenotomy. We have seen that Dr. Noyes had attributed these conditions to general weakness of the ocular muscles, and it is well to bear both causes in mind. Dr. Stevens finds that the whole of a faulty tendency is rarely revealed by a test with prisms, and that part still remains latent, which indeed might have been expected; and says that "instances of even approximate balancing of the eye muscles in anisometropia are rather exceptional," and also that hyperphoria is generally associated with monocular amblyopia, which he attributes to mental suppression of one image during occasional periods of diplopia. This reason appears scarcely valid, for however legitimate it may be to speak of "*amblyopia ex anopsiā*" in cases of complete and long-standing strabismus, we can scarcely suppose that intermittent diplopia could bring it about. Yet were the diplopia persistent, the case would not be one of hyperphoria, but of hypertropia. The cause is more probably to be found in the same

unilateral defect of development as that to which the anisometropia and the hyperphoria itself are due. Dr. Stevens prefers to perform a very delicate tenotomy for cases of heterophoria rather than to prescribe prisms. Dr. Webster, following in his footsteps, also performs tenotomy, but only when all other means have failed and the nervous consequences of the anomaly are serious. He places the eye under the influence of cocaine, and tests the muscular equilibrium by prisms at intervals through the operation.—("Oph. Review," vii. 363).

An account of some ingenious devices for testing the conjugate tendencies of the eyes will be found in papers by Dr. Ward A. Holden, of Cincinnati, in the "Archives of Ophthalmology," Sept. 1887, p. 295, and Dec. 1887, p. 403.

RESULTANT PRISMS, as recommended on p. 98, are prescribed as follows. Let R be the deviating angle of the prism required to combine the effects of a vertical and horizontal prism: let V be the deviating angle of the vertical prism, and H that of the horizontal

one ; then $\text{Sin. } R = \sqrt{\text{Sin.}^2 V + \text{Sin.}^2 H}$;
and if r be the angle of rotation from the
vertical,

$$\text{Sin. } r = \frac{\text{Sin. } H}{\text{Sin. } R}.$$

We thus obtain both the strength and position
of a prism whose effect will be the resultant
of the other two, and an ordinary table of
logarithmic sines makes the calculation a
very brief one.

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"It is well known to the profession that Dr. SAUNDBY has long been an earnest worker in the elucidation of questions connected with Bright's disease. We may say at once that we have read the book with great pleasure and profit, and we VERY WARMLY RECOMMEND ITS STUDY BY THE PROFESSION. The size of the work is so modest (290 pages) that on that ground alone it invites perusal, and the volume recommends itself from the fact that it will easily find a nook on the library shelves. As might have been expected from Dr. SAUNDBY, the matter, taken both from personal observation and wide general reading, is accurate, well digested, and concisely and perspicuously arranged. For those who wish to follow up the various points discussed there is a bibliography given at the end of each chapter, and the text is illustrated by many excellent and useful figures. . . . Considering, therefore, the prevalence of the diseases discussed, their importance, and the hazy notions held by many regarding them, we believe that this little work will supply a great want, and will meet with the large measure of success which it deserves. We may add that the book is most excellently and carefully printed."—*Illustrated Medical News*, April 6th, 1889.

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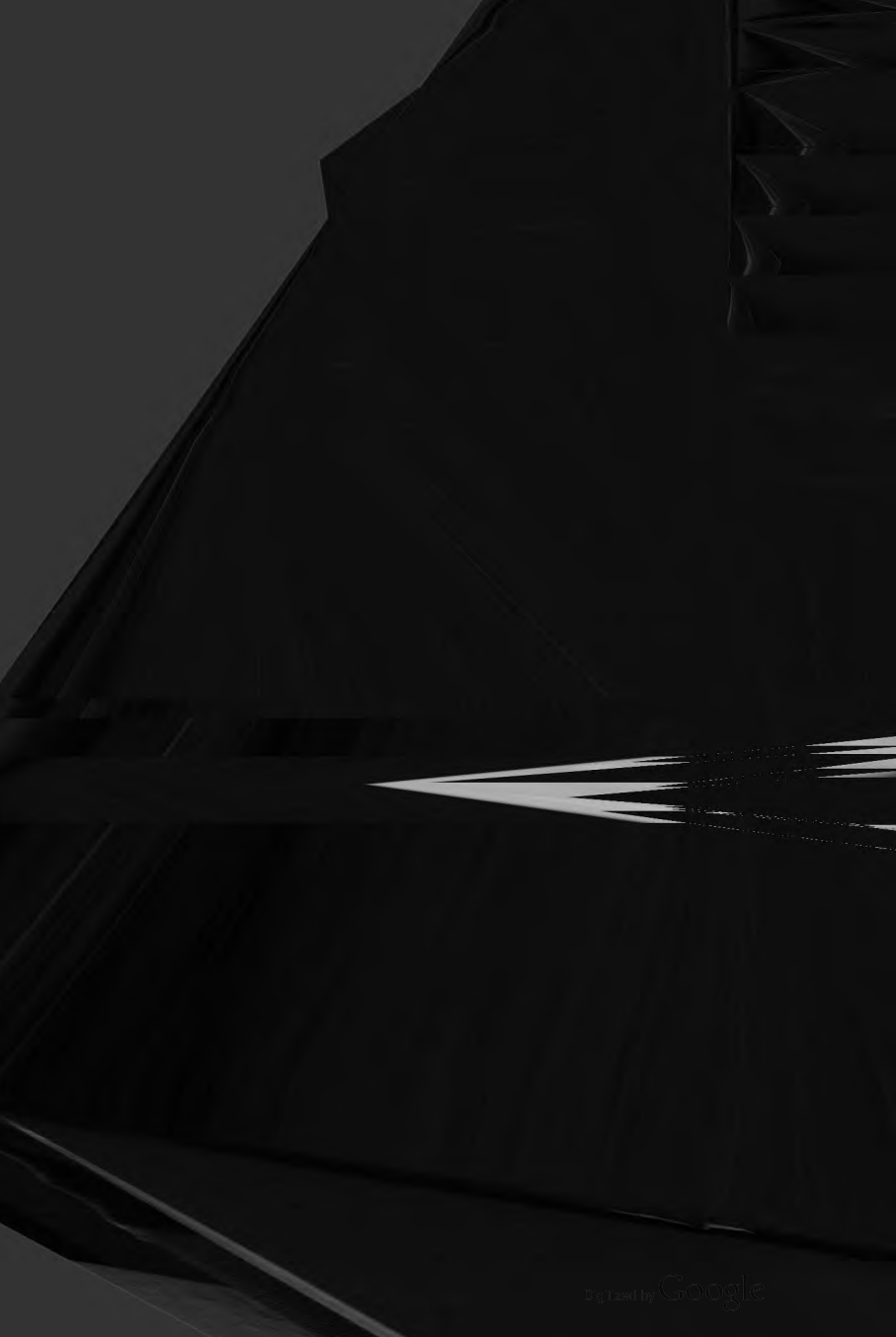
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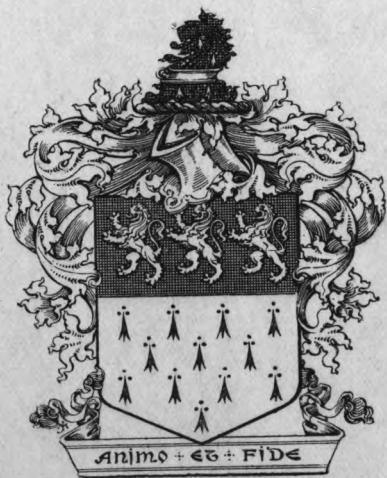
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REFRACTION OF THE EYE

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SHORT SIGHT, LONG SIGHT

AND

ASTIGMATISM

W. H. W. H. W. H.

SHORT SIGHT, LONG SIGHT

AND

ASTIGMATISM

AN ELEMENTARY GUIDE TO THE REFRACTION
OF THE EYE.

BY

GEORGE FREDERICK HELM

M.A.CANTAB., M.D., F.R.C.S.^F

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PREFACE

THE object of this book is to place before Students and Practitioners an elementary treatise on the errors of refraction of the eye, and to endeavour to explain in simple language their nature and the means whereby they may be satisfactorily corrected.

It is thus intended to serve as an introduction to the more advanced manuals on the same subject.

I regret that I am compelled, having in view the scope of the book, to omit all reference to the valuable aid which the direct Ophthalmoscopic Examination and Retinoscopy afford us in estimating and correcting errors of refraction.

To Mr Lang, Ophthalmic Surgeon to the Middlesex Hospital, I am much indebted for many valuable suggestions.

June 1st, 1886.

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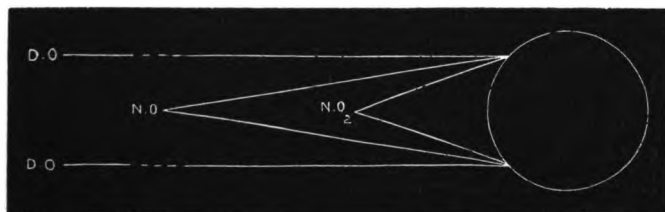
REFRACTION

CHAPTER I

LIGHT

1. Rays of light proceeding from an object which is situated at a distance of 6 metres (1 metre = 39·37 inches nearly) or more from the observer are considered as proceeding from that object in parallel lines, and therefore they fall upon the eye of the observer as parallel rays of light (Fig. 1).

FIG. 1.



D. O. = Parallel rays from a distant object.

N. O. = Diverging rays from a near object.

N. O.₂ = Rays of increased divergence from a nearer object than N. O.

1 inch = 1 metre.

2. Rays of light proceeding from an object which is situated at a distance of less than six metres from the observer are considered as proceeding from that object in lines which *diverge*, and therefore they fall upon the eye of the observer as diverging rays of light (Fig. 1).

3. The amount of this divergence *increases* the nearer the object is brought to the eye of the observer, therefore the nearer the object is to the eye of the observer the more divergent is the direction in which the rays from it will fall upon his eye (Fig. 1).

4. The amount of divergence of the rays *decreases* the further the object is removed from the eye of the observer, and when the object has been removed to a distance of 6 metres or more the rays proceeding from it are considered as being parallel.

5. Therefore a *distant object* is one which, being situated at a distance of 6 metres or more, has rays of light proceeding from it in parallel lines.

6. A *near object* is one which, being situated at a distance of *less* than 6 metres, has rays of light proceeding from it in diverging lines, such lines becoming more and more divergent the nearer the object is brought to the eye of the observer.

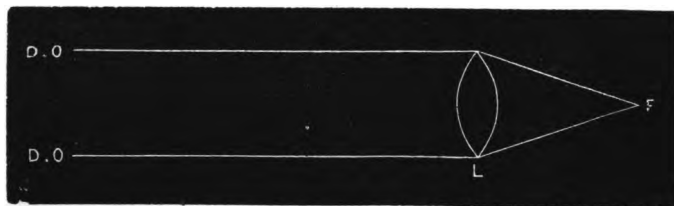
7. Spherical lenses are either biconvex or biconcave. Biconvex lenses are called + lenses. Biconcave lenses are called - lenses.

8. Rays of light when passed through a spherical lens or through a prism have their direction altered. They are then said to have been refracted by the lens or by the prism.

9. Supposing that parallel rays of light from a distant object are passed through a + lens (L, Fig. 2) the rays then become refracted and are brought to a point at F, and are said to be focussed at F.

This point F is therefore called the *principal focus* of the lens L (Fig. 2).

FIG. 2



D. O. = Distant object. L. = Lens. F. = Focus.

10. Rays of light passing through a spherical lens or a prism are always refracted towards the thickest part of the lens or prism.

11. The distance between the + lens and its principal focus (F, Fig. 2) will depend upon the degree of convexity of the lens.

12. If the distance between the + lens and F is 1 metre then the lens is called a lens of 1 metre focus, that is, it is a lens which will bring parallel rays to a focus at a point 1 metre distant from the lens.

Such a lens is taken as the unit for calculation, and is called a lens of 1 diopetre, or shortly +1 D. spherical lens.

13. If the distance between the lens and F is only $\frac{1}{2}$ metre, it is evident that a lens which can bring parallel rays to a focus at a point $\frac{1}{2}$ metre distant from

it must be a lens of twice the refracting power of that lens which focusses similar parallel rays at a distance of 1 metre.

Hence, a lens whose focus is $\frac{1}{2}$ metre (50 cm.) distant is called a lens of 2 dioptries or + 2 D.

14. If the distance between the lens and the focal point F is $\frac{1}{3}$ metre then the lens has three times the strength of that lens which requires a length of 1 metre between it and F . Thus :

A lens of 1 diopetre focusses paral-

lel rays at a distance of . . . 1 metre or 100 cm.

A lens of 2 ,, ,, $\frac{1}{2}$ metre or 50 cm.

A lens of 3 ,, ,, $\frac{1}{3}$ metre or 33 cm.

A lens of 4 ,, ,, $\frac{1}{4}$ metre or 25 cm.

15. Hence it follows that the distance between the lens and its focus, or its focal distance, can always be found by dividing 1 metre (=100 cm.) by the number of dioptries of the lens. Thus :

$$\frac{100 \text{ cm.}}{1 \text{ D.}} = 100 \text{ cm.} = 1 \text{ met.} = \text{focal distance of } + 1 \text{ D. lens.}$$

$$\frac{100 \text{ cm.}}{2 \text{ D.}} = 50 \text{ cm.} = \text{focal distance of } + 2 \text{ D. lens.}$$

$$\frac{100 \text{ cm.}}{3 \text{ D.}} = 33 \text{ cm.} = \text{,, ,, of } + 3 \text{ D. lens.}$$

$$\frac{100 \text{ cm.}}{4 \text{ D.}} = 25 \text{ cm.} = \text{,, ,, of } + 4 \text{ D. lens.}$$

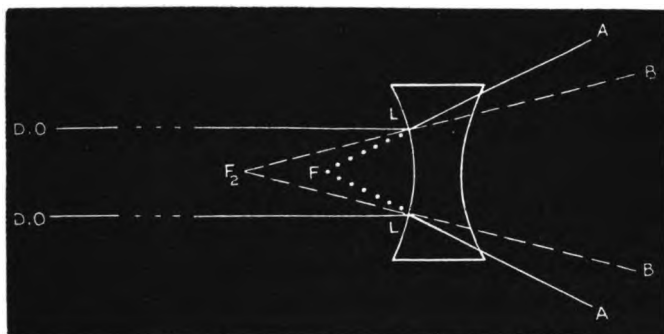
And so on.

16. Therefore the higher the number of the lens in dioptries the greater is its power of refracting rays of light which pass through it, and so the lenses +

2 D. + 3 D. + 4 D., have respectively twice, three times, and four times the power of a lens of + 1 D.

17. If the rays of light pass through a biconcave or — lens they are refracted (in accordance with S 10) towards the thickest part of the lens (Fig. 3).

FIG. 3.



D. O. = Parallel rays of distant object. L. = Lens.

Thus, parallel rays from a distant object, D O, passing through a — lens, L, would be refracted towards A, the thickest part of the lens, and the focus (F) would be situated on that side of the lens on which the distant object lies, *i. e.* between the object and the lens. And it would be at that point at which the diverging rays, A, would meet if they were continued backwards towards the object; and such a focus is called a *virtual* focus.

18. Hence the more divergent the rays are after their passage through the — lens the nearer will F be

to the lens, and the more powerful is the lens ; a lens of lesser power would cause the rays to diverge to a lesser extent, and consequently, if continued backwards, they would meet at a point more remote from the lens.

In Fig. 3 let the parallel rays from $D O$ be refracted into the direction of the lines $L A$.

Then, the lines $A L$, when continued backwards, would meet at F , which is consequently the virtual focus of the lens.

But if the rays were refracted to a lesser extent so as to take the direction of the lines $L B$, then the lines $B L$ when continued backwards would meet at F_2 , which in this case would be the virtual focus of the lens, and this lens would in that case be a less powerful — lens than one is which would have its virtual focus nearer to the lens than F_2 .

19. Therefore, in speaking of — lenses, the greater the *divergence* given by them to parallel rays the more powerful is the lens ; and in speaking of + lenses the greater the *convergence* given by them to parallel rays the more powerful is the lens.

If parallel rays are passed through a biconcave or — lens of — 1 D. they would diverge to such an extent that such rays would meet at a point F , situated on the *same* side of the lens as is the object, and the point F (*i. e.* focal point) would be at a distance of 1 metre from the lens.

20. Hence (1) a — lens of 1 diopetre has its virtual focus for parallel rays at a distance of 1 metre from the lens and on the same side of it as is the object.

(2) A lens of -2 D. has its focus at $\frac{1}{2}$ metre or 50 cm. and on same side as is the object.

(3) A lens of -3 D. has its focus at $\frac{1}{3}$ metre or 33 cm. and on the same side as is the object.

(4) A lens of -4 D. has its focus at $\frac{1}{4}$ metre or 25 cm. and on the same side as is the object. And so on.

21. And the focal distance of a $-$ lens is found in exactly the same way as the focal distance of a $+$ lens is found (*vide* 15) by dividing 1 metre (100 cm.) by the number of the dioptries of the lens. Thus :

$$\frac{100 \text{ cm.}}{-1 \text{ D.}} = 100 \text{ cm.} = 1 \text{ metre} = \text{focal distance of } -1 \text{ D.}$$

$$\frac{100 \text{ cm.}}{-2 \text{ D.}} = 50 \text{ cm.} = \text{focal distance of } -2 \text{ D.}$$

$$\frac{100 \text{ cm.}}{-3 \text{ D.}} = 33 \text{ cm.} = \text{,, ,, of } -3 \text{ D.}$$

$$\frac{100 \text{ cm.}}{-4 \text{ D.}} = 25 \text{ cm.} = \text{,, ,, of } -4 \text{ D.}$$

22. Diverging rays of light proceeding from a near object (2) and passing through a $-$ lens, will be refracted more than parallel rays passing through the same lens would be, because coming from a near object they are already divergent rays before they meet the $-$ lens, which causes them to diverge still further.

Important points to be remembered are :

23. That rays proceeding from an object placed at a point which is at the same distance from a $+$ lens as is its focal point, will emerge from such a lens as parallel rays (Figs. 4 and 5).

24. That rays proceeding from an object placed at a point which is *beyond* the focal point of a lens will emerge from that lens as *converging* rays (Fig. 6).

25. That rays proceeding from an object placed at a point which is *within* the focal point of a lens will emerge from that lens as *diverging* rays (Fig. 7).

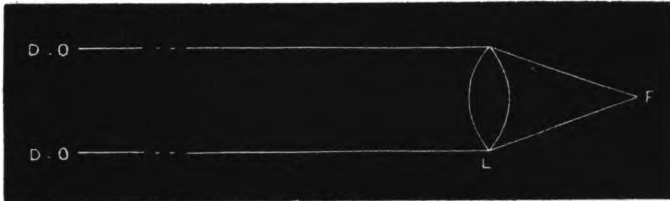
It has been mentioned before that parallel rays from a distant object passing through a + 1 D. lens are focussed at F distant 1 metre from the lens (Fig. 4).

26. But if the object be placed at the point o (Fig. 5) the same distance from the + 1 D. lens that the point F is, say a distance of 1 metre, then the rays of light from o would pass out of the lens as parallel rays, because the point o is situated at the exact focal distance of the + 1 D. lens (Fig. 5).

27. Thus, parallel rays of light (Fig. 4) meet at F , and diverging rays of light from an object at F would pass out of the lens as parallel rays (Fig. 5).

28. But if the object be removed further away (Fig. 6) from F the focus of the + 1 D. lens (*i. e.* to a distance beyond 1 metre) the rays of light from it would no longer pass out of the lens as parallel rays, but as the object receded gradually further and further away from F so would the rays of light pass out of the lens as more and more converging rays; and when the object had arrived at a point o (Fig. 6), distant 2 metres from the + 1 D. lens (*i. e.* to a point at *double* the focal distance of the lens) they would have converged sufficiently to meet at the point F_2 , which is distant also 2 metres from the lens.

FIG. 4.



D.O. = Distant object. L. = Lens. F. = Focus.

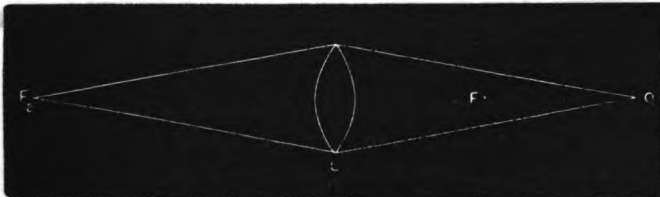
FIG. 5.



O. = Object situated at the same distance from the lens that the focal point of the lens is.

P. R. = Parallel rays.

FIG. 6.



F. = Point which would be the focus of parallel rays passing through L.

O. = Object at double the focal distance of the lens L.

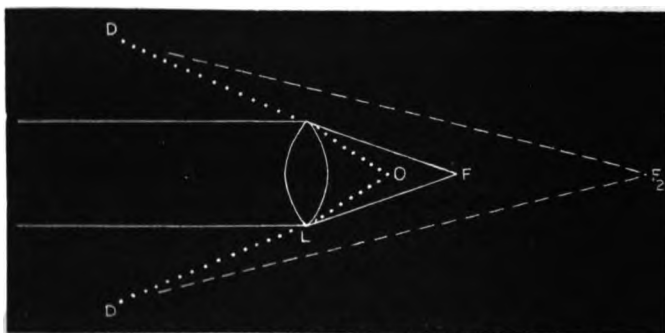
F₂ = Conjugate focus of object at o.

29. Hence, whenever the object is situated at double the focal distance of the lens, the focus of that object will also be situated at double the focal distance of the lens, but on the other side of it as at F_2 (Fig. 6). And an object at F_2 would be focussed at o (Fig. 6). So that in such a case the object and its focus can be transposed.

30. The points F_2 and o are therefore known as conjugate foci.

31. But if the object, instead of being placed beyond the focal point F of a $+1$ D. lens, be now placed as at o , Fig. 7, a point *within* the focal distance, F , of the

FIG. 7.



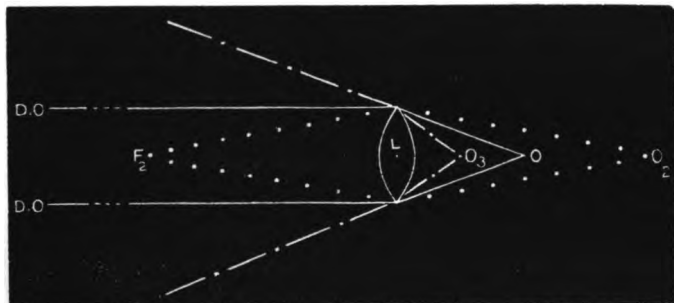
O . = Object placed within focal distance of the lens.

F_2 . = Virtual focus of O .

lens, then the rays proceeding from o , a point *nearer* to the lens than is the point F , would fall upon the lens as much more divergent rays than if they had come from the more distant point F , and consequently the lens is not equal to refracting them even into parallel rays as it would do if they came from the focus,

but they would emerge from the lens as diverging rays at D and would be lost in space, and their focus would be a virtual one on the same side of the lens as that on which the object is situated, say at F_2 (Fig. 7).

FIG. 8.



To recapitulate—

A. Let L be a + lens with its focus at o (Fig. 8). Then the rays from an object at o will emerge from the lens as parallel rays (DO).

B. Let o_2 be an object situated outside (*i. e.* beyond) the focal point o , and let it be at double the distance from L that o is. Then the rays from o_2 having passed through L will be focussed at its conjugate focus F_2 (30).

C. Let o_3 be an object situated inside (*i. e.* within) the focal point o . Then rays proceeding from an object at o_3 after having passed through the lens will emerge from the lens as diverging rays. Thus :

Rays from o the focus emerge from the lens as parallel rays.

Rays from o_2 outside the focus emerge from the lens as converging rays.

Rays from o_3 inside the focus emerge from the lens as diverging rays.

But if the object be gradually moved from o_2 so as to approach the lens, then, in proportion as the object approaches o , so will the rays from it tend to gradually assume on the other side of the lens the same direction as they would have if they had come from o , and as o is the focus that direction would be parallel. And when the object has arrived at o the rays from it will then pass out in a parallel direction, because o is at the same distance from the lens that its principal focus is.

And if the object be moved from o to a point still nearer to the lens, then in proportion as the object approaches the lens so will the rays from the object emerge from the lens with an increasing degree of divergence.

And, *vice versâ*, if we start the object from the point o_3 the rays from it at starting will emerge from the lens as diverging rays; and when the object has arrived at o the rays will have become parallel on the other side of the lens; and by the time that the object has arrived at o_2 , the parallel rays on the other side of the lens will now have become converging with a focus at the conjugate focus F_2 .

CHAPTER II

DEFINITIONS OF EMMETROPIA, MYOPIA, AND HYPER-
METROPIA.

32. An eye in connection with refraction may be considered as made up of:

(1) Certain refractive media (cornea, aqueous humour, lens), which together possess the same power of refracting rays of light as does a + lens.

(2) The retina on which the rays of light *should* be focussed after that they have passed through the refracting media.

But it is not every eye that possesses this power of focussing *on* the retina the rays of light which have passed through the refracting media. That is, there exists in some eyes certain errors of refraction which prevent the rays of light from being focussed on the retina.

33. In order to compare errors of refraction in different eyes a certain standard of perfection is agreed upon.

A normally refracting eye is one which, when in a state of rest (with all efforts of accommodation in abeyance, and therefore acting like a simple refracting + lens) will focus on the retina the parallel rays proceeding from a distant object.

34. Such an eye is called an emmetropic eye (Fig. 9), and its possessors are called emmetropes.

FIG. 9.—Emmetropic Eye.

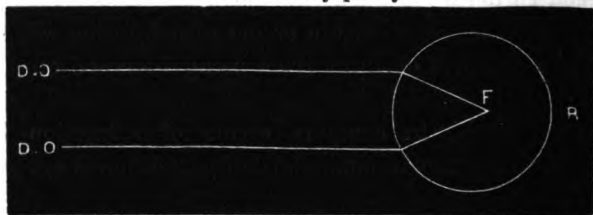


D. O. = Distant object, rays from which are focussed at F. on retina.
R. = Retina.

35. All eyes deviating from the above standard of perfection are called ametropic eyes. Ametropic eyes are of two kinds.

36. (A) An eye which, without any effort of the will (*i. e.* acting like a + lens) focusses *in front* of the retina instead of *on it*, the parallel rays from a distant

FIG. 10.—Myopic Eye.

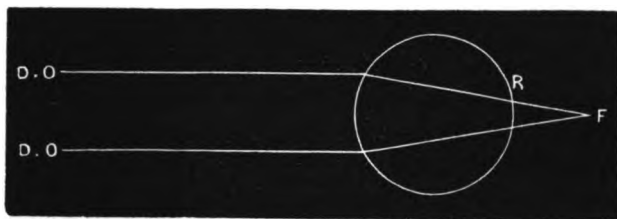


D. O. = Distant object, rays from which are focussed at F. in front of the retina.
R. = Retina.

object, is called a myopic eye (Fig. 10) and its possessor is the subject of *myopia*.

37. (B) An eye which, without any effort of the will (*i. e.* acting like a + lens), focusses *behind* the retina instead of *on* it, the parallel rays proceeding from a distant object, is called a hypermetropic eye (Fig. 11), and its possessor is the subject of *hypermetropia*.

FIG. 11.—Hypermetropic Eye.



D. O. = Distant object, rays from which are focussed at F. behind the retina.

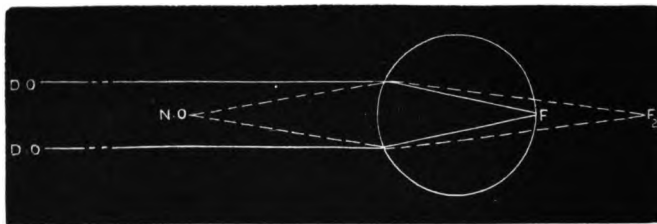
R. = Retina.

CHAPTER III

ACCOMMODATION

It has been shown (33) that the emmetropic eye when in a state of rest will focus on the retina parallel rays from a distant object, and vision of such an object would be distinct. It follows, therefore, that if the emmetropic eye continues in a state of rest, the diverging rays from a near object must be focussed behind the retina (Fig. 12) and vision of such an object would consequently be imperfect.

FIG. 12.



D. O. = Distant object, with parallel rays proceeding from it.

N. O. = Near object, with diverging rays proceeding from it.

F. = Focus for parallel rays.

F₂. = Focus for diverging rays from N O.

But supposing that the refracting media of the emmetropic eye were by some means to be made more

convex when looking at the near object, then the divergent rays from this near object *might* be focussed on the retina instead of behind it.

This is just what does take place when the emmetropic eye views a near object, for in the eye (whether emmetropic or ametropic) there *does* reside an ability to call into play an increase in its refractive power, whereby the eye which, at one moment, when in a state of rest, can obtain a distinct view of distant objects, can now at another moment suddenly view a near object.

But the eye is then considered as being no longer in a state of rest, for it accomplishes this vision of near objects by altering the shape and position of the lens, making the refraction of the eye for the moment more powerful, and therefore the diverging rays from a near object, which would have been focussed behind the retina, if the lens had retained the same shape as it had when viewing a distant object (Fig. 12) are now in consequence of the increased convexity of the lens, enabled to be focussed on the retina (44).

38. This voluntary alteration in the refractive power of the eye is called its power of accommodation.

CHAPTER IV

MYOPIA

WE have seen (36) that a myopic eye is one which, in a state of rest (*i. e.* with no exercise of accommodation), focusses *in front* of the retina instead of on it, the parallel rays from a distant object.

39. This error of refraction might arise from three causes.

(A) The myopic eye may be too long in its antero-posterior diameter, *i. e.* from the cornea in front to the retina behind, so that the retina is removed too far back from the refracting media of the eye ; thus leading to the focussing of the rays of light in front of it.

(B) The refracting media of the eye may be too convex, and so they bring the rays *too soon* to a focus, *i. e.* to a point in front of the retina.

(C) Too high an index of refraction of the *transparent* media of the eye.

40. Although some authorities doubt the existence of the cause (2 and 3), yet perhaps it may simplify future explanations if we regard the myopic eye as one which errs in having its refractive media too convex, since such a definition at once suggests the general remedy for myopia, viz. biconcave or — lenses.

41. It follows, from the definition of the myopic eye,

that such an eye is unable to see any object at a distance (6 metres or more) because it cannot focus on the retina the parallel rays. But if diverging rays are presented to a myopic eye, then the refracting media, which possess too much convexity for the focussing of *parallel* rays, may have such an extra amount of convexity as will focus on the retina rays of a certain amount of divergency, thereby giving distinct vision for them.

Yet, if the rays of light have too great an amount of divergency for the eye under consideration, then the rays would be focussed behind the retina, and vision would be again indistinct, unless accommodation is brought into use. So that in Fig. 13 the rays from $D O$ (distant object) are focussed at F .

But the rays from $N O$ (near object) have just that amount of divergency as will, so to say, fit the error of increased refraction of the eye under consideration, and they are focussed at F_2 .

Suppose a book situated at $N O$, then this myopic eye would be able to read the type, and if the book is removed a little further *from* the eye than $N O$, then the rays of light would no longer be focussed on the retina at F_2 , but just as the book was removed further off, so the focus of its rays would *recede* from the retina at F_2 and would gradually approach the point F . Of course, therefore, vision is indistinct directly the type begins to be removed further from the eye than $N O$.

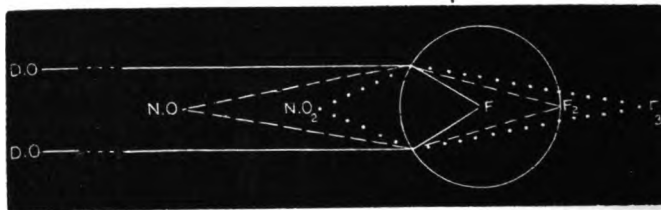
42. Hence $N O$ is really the *farthest* point of distinct vision for this myopic eye.

43. The far point of distinct vision is spoken of as the punctum remotum, or p. r.

But suppose that the type, which this myopic eye can read distinctly when placed at $N O$, is now brought *nearer* to the eye than $N O$, *i. e.* towards $N O_2$.

44. Then, the nearer it is to the eye the further *behind* the retina is its focus, and vision would again

FIG. 13.



be indistinct unless the eye brought its accommodation into use, and if by using accommodation the type can be read at $N O_3$:

45. Then $N O_3$ would be the *nearest* point of distinct vision for this myopic eye.

46. The near point of distinct vision is spoken of as the punctum proximum, or p. p.

So that, to recapitulate—

47. In the emmetropic eye the far point of distinct vision is at an infinite distance, *i. e.* at a distance of 6 metres or more.

48. In the myopic eye the *far* point is at a finite distance, *i. e.* at a distance of less than 6 metres, varying according to the amount of the myopia.

49. That there is a *near* point of distinct vision both

in emmetropic and myopic eyes is the result of the exercise of accommodation.

50. But in the myopic eye, as the *far* point may be inconveniently near to the eye for reading, &c., of course the near point would be still more inconvenient for any practical use.

51. Hence, in myopia of any extent, there is hardly any use for accommodation, consequently in myopia the ciliary muscle from disuse is usually atrophied.

52. The accommodation, therefore, in a myopic eye is defective from disuse, and if called into play it can only be exercised at the expense of great straining of the eye and other serious results.

Therefore, as we shall see further on, when remedying the myopia by means of spectacles we are always careful to select (except in cases of slight myopia in young subjects) such lenses as will in their use entail no effort of accommodation, with its attendant risks, in highly myopic eyes.

53. The degree of myopia is measured by the distance which the punctum remotum is from the eye.

54. If it is distant 50 cm., then the eye has 2 dioptries of myopia.

$$\text{Because } \frac{100 \text{ cm. (1 metre)}}{50 \text{ cm.}} = 2 \text{ D.}$$

If it is distant 25 cm., then the eye has 4 dioptries of myopia.

$$\text{Because } \frac{100 \text{ cm.}}{25 \text{ cm.}} = 4 \text{ D.}$$

55. So that the further the distance of the punctum remotum from the eye the less is the myopia.

For it is evident that the eye which has its punctum remotum at 50 cm. will deviate less from the emmetropic eye (which has its punctum remotum at infinity) than does that eye which has its punctum remotum at only 25 cm. distance from the eye, and in the former case there is myopia of -2 D.

$$\text{Because } \frac{100 \text{ cm.}}{50 \text{ cm.}} = -2 \text{ D.}$$

And in the latter case there is myopia of -4 D.

$$\text{Because } \frac{100 \text{ cm.}}{25 \text{ cm.}} = -4 \text{ D.}$$

56. Because the error of refraction in myopia shows itself by the punctum remotum being at a finite instead of at an infinite distance, it follows, that the remedy will be to place in front of the eye such a lens as will push back the punctum remotum from a finite to an infinite distance.

Suppose that we have a case of myopia of 7 dioptries, which is equivalent to saying that the punctum remotum is at 14 cm. distance from the eye.

$$\text{Because } \frac{100 \text{ cm.}}{7 \text{ D.}} = 14 \text{ cm. (nearly).}$$

In other words, this eye in a state of rest can focus on the retina rays of light which have just that amount of divergence which those rays have which come from an object at 14 cm. distance.

Now, if a -7 D. lens be placed in front of this myopic eye, it will give to the parallel rays which come from an infinite distance just that exact amount

of divergence which they would have if they had come from the finite distance of 14 cm.—the distance at which there is distinct vision in this myopic eye.

$$\text{Because } \frac{100 \text{ cm.}}{14 \text{ cm.}} = -7 \text{ D.}$$

This eye can now, with a -7 D. lens, be considered as an emmetropic eye, with distinct vision for *distant* objects.

If this is the desire of a patient with myopia of 7 dioptries we have theoretically met his wishes by means of a -7 D. lens.

But in practice we find that a lens of -1 D. or -1.5 D. less than -7 D. (*i. e.* -6 D. or -5.5 D.) would be most suitable because a -7 D. lens might possibly over-correct the myopia, *i. e.* the focus for distant objects, which was originally too far forwards in front of the retina, may possibly now, by means of the $-$ lens, be pushed *too far back* so as to be behind the retina.

In such a case, the eye by exercising accommodation will bring the focus forward again and so put it on the retina instead of behind it.

But for reasons given in 52, 63, one object to be aimed at in cases of myopia is to take care that accommodation is not called into play.

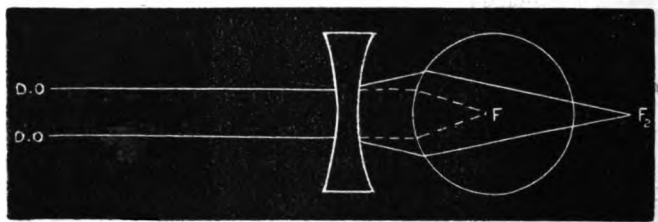
57. And, therefore, to ensure against over-correcting the myopia by means of any lenses, the rule is to give in such cases the *weakest* lens which will give distinct vision.

So that if the patient on being fitted with trial lenses has equally distinct vision for distant objects with a -5 D. or -6 D. or -6.5 D. or -7 D. :

Then the -5 D. would be the proper lens for distant vision, because it gives the greatest assurance against over-correction of the myopia with its consequent accommodative effort, which we so much wish to avoid in these cases.

58. To show what is meant by over-correcting the myopia, let Fig. 14 represent the parallel rays from a

FIG. 14.



D. O. = Rays from distant objects.

F. = Myopic focus of rays from D. O.

F₂ = Focus of the over-corrected myopia.

distant object, which would in this myopic eye be focussed in front of the retina at F .

But if they were passed through a too powerful $-$ lens they would be rendered so divergent that they may be now focussed behind the retina at F_2 , and indistinct vision would again result from the over-correction of the myopia.

But this patient, by using his accommodation, could bring the focus forwards again on to the retina, and notwithstanding the over-correcting lens he might say that his vision is distinct. If it is so, he must have been using his accommodation.

59. In order then to test whether, in making this statement of distinct vision, he has been using his accommodation, we test him with a — lens of less power. Perhaps he will still state that he sees correctly—in that case he has been using his accommodation to a lesser extent than he did when tried with the more powerful lens.

So we gradually reduce the power of the trial lenses (and each reduction, if accompanied by a statement of clear vision, means therefore a corresponding diminution of the accommodation used) till we come to a lens with which vision is no longer distinct, *i. e.* the accommodation has been dropped as being no longer of any use, and we have brought the focus back to a point in front of the retina.

We then revert to the *weakest* lens, which gave distinct vision, and feel sure that the patient's accommodation is not being used with it. For the difference between the strongest (over-correcting) lens and the weakest lenses with which vision was distinct, must clearly represent the power of the accommodation used.

60. But most myopic patients require something more than distinct vision for *distant* objects. They require to be able to read, write, work, &c., at greater distances from their eyes than their natural far point of distinct vision will allow them to do.

61. This of course applies to cases of high myopia, for where the myopia is slight, say of — 3 D or even — 4 D the natural far points would be

$$33 \text{ cm. } \left(\frac{100}{3 \text{ D.}} = 33 \text{ cm.} \right) \text{ and } 25 \text{ cm. } \left(\frac{100}{4 \text{ D.}} = 25 \text{ cm.} \right)$$

respectively, at which distances reading can be carried on at no inconvenience as far as the distance of the book is concerned.

Glasses for distant vision only might be required in such cases.

62. But where the myopia is of high degree it may at first be thought that the lens which fully corrects the myopia for distant objects, would be a proper lens for near objects, because the fully-correcting lens would have made the myopic eye into an emmetropic eye, and an emmetropic eye can see near objects.

63. But it sees near objects by exercising its accommodation, and in myopia there are two objections to depending on accommodation for vision of near objects.

(A) "The fact that in myopia the ciliary muscle is wasted and hence there is deficient accommodation, whereas a fully correcting lens requires full accommodation for near vision, and since in myopia the power of accommodation is weakened from disease of the ciliary muscle, overstraining of the eye would result and so cause discomfort, if nothing worse.

(B) "By a fully correcting — lens the retinal images would be so much diminished in size that the patient is tempted to enlarge the images again by bringing the object nearer, thus doing away with much of the benefit which his lenses ought to bring to him."
(*Nettleship.*)

64. Hence in higher degrees of myopia we require for distinct *near* vision such a lens as will place the

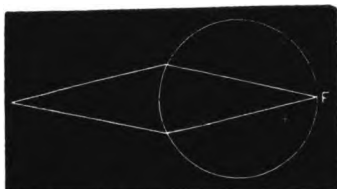
far point at a greater distance from the eye than at which the natural refraction of the eye places it.

Suppose that we are dealing again with an eye which possesses 7 dioptries of myopia, such an eye will have its far point at 14 cm. from the eye—

$$\left(\frac{100 \text{ cm.}}{7 \text{ D.}} = 14 \text{ cm.} \right).$$

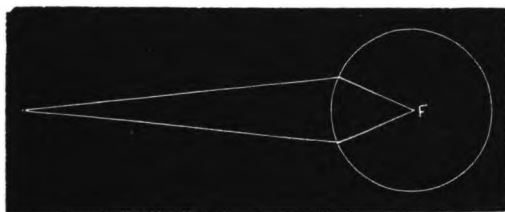
Let us suppose that we require to remove this far point to a distance of 30 cm. (*vide* Figs. 15, 16, 17).

FIG. 15.



Diverging rays from 14 cm. focussed on retina.

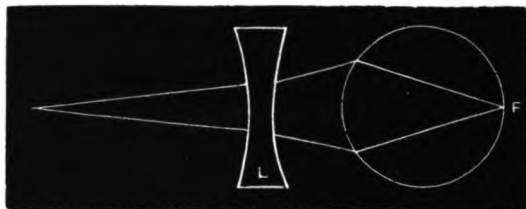
FIG. 16.



Less diverging rays from 30 cm. focussed in front of retina.

Rays coming from an object at 30 cm. distance will have *less* divergence than they would have if they came from an object 14 cm.

FIG. 17.



Increased divergence given by means of lens to rays from 30 cm., so as to give them the same amount of divergence as they would have if they came from 14 cm. ; consequently they are focussed on the retina, and the far point is 30 cm. instead of 14 cm.

Now, an eye with 7 D of myopia has distinct vision for an object distant 14 cm., because that is its natural far point.

Hence what we require is to give to the less diverging rays from 30 cm. such an increase in their divergence as will make them appear as if they came from a distance of 14 cm.

That being done these rays from 30 cm. are now properly focussed and distinct vision at that distance results.

Now, a - 7 D. lens (which is the fully correcting lens in this case) will give to the parallel rays such an amount of divergence as they would have if they came from a distance of 14 cm.

But we require to give to the rays a less amount of divergence than that ; we only require that they should have the lesser divergence of an object at 30 cm.

Therefore from such a lens as has a focal distance

of 14 cm. (— 7 D.) we subtract that lens whose focal distance is 30 cm. (— 3·25 D.).

Our sum will stand thus :

$$\begin{array}{r} - 7 \text{ D.} \\ - 3\cdot25 \text{ D.} \\ \hline - 3\cdot75 \text{ D.} \end{array}$$

And a lens — 3·75 D. will be the lens required.

But the patient should be cautioned against using his spectacles to see objects situated at a shorter distance than that for which they are adapted (30 cm.) because in that case the divergence of the rays from the object are increased the nearer it is brought to the eye, and such rays would be focussed behind the retina, producing confused vision, though by using his accommodation distinct vision would be restored, but the use of accommodation, we have before said, is hurtful, therefore the patient should take care to place his work at his allotted distance from the eye, though his difficulty in so doing is increased by the fact that there is a constant temptation to overstep his distance, because the nearer the object is to the eye the larger is the image which he obtains on his retina.

Hence watchfulness and attention are required on the part of the patient.

65. To sum up then :

In young people in whom the myopia is not extreme, say — 2·5 D., and in whom in consequence of youth the ciliary muscle has not yet had time to become atrophied from disuse, we may in these cases supply lenses which fully correct the myopia for distant objects.

In these cases we have no hesitation in calling upon their accommodation to supply them with distinct vision for near objects.

66. Also in the case of myopia of not above say — 7 D. occurring in persons not over twenty-five years of age, we may try fully correcting glasses, provided they show no signs of disease of the fundus of the eye. By giving them fully correcting glasses we rely on the accommodation coming into play and giving near vision. By wearing these fully correcting lenses constantly “the ciliary muscle may be coaxed into action, and may eventually be brought up to the normal working power.” (*Lang.*)

67. In older people in whom the myopia is not extreme we may also give lenses which fully correct the myopia for distant objects, but with the caution that they should not be used for near objects.

Their myopia not being extreme, their natural far point (without lenses) will be situated at a convenient distance from the eye for reading, &c.

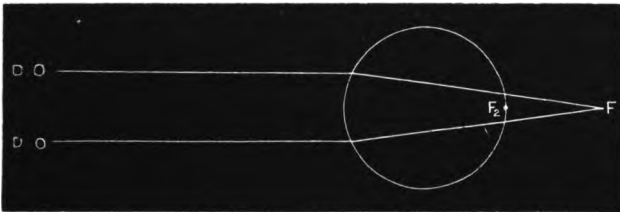
68. But in extreme myopia we give glasses in accordance with Section 64.

CHAPTER V

HYPERMETROPIA

69. In the hypermetropic eye the parallel rays from a distant object are focussed behind the retina instead of on it, and this error of refraction may theoretically arise from three sources (Fig. 18).

FIG 18.—Hypermetropic Eye.



D. O. = Rays from distant object.

F. = Focus of such rays behind retina.

F₂. = Focus of such parallel rays, brought forwards by means of the exercise of accommodation.

(A) The hypermetropic eye may be too short in its antero-posterior diameter, *i. e.* from the cornea in front to the retina behind, so that the retina is moved too far forwards, and is too near to the refracting media of the eye.

(B) The refracting media of the eye may not be

sufficiently convex ; thus becoming deficient in refractive power they are unable to focus on the retina the parallel rays of light from a distant object.

(c) Too low an index of refraction of the transparent media.

70. In all these cases the same thing will happen, viz. that the parallel rays of light from a distant object meet the retina before they have been sufficiently refracted to come to a focus, *i. e.* the principal focus of the eye is situated behind the retina (Fig. 18) and vision for distant objects is indistinct.

71. But if, *before* they meet the refractive media of the eye, the parallel rays from a distant object can be made to converge somewhat, then the hypermetropic eye, with its feeble refracting power (70), may be equal to focussing on the retina (instead of behind it) such already slightly converging rays.

In this case the hypermetropia is corrected by the lens, provided of course that its convexity is suited to the amount of the hypermetropia.

But though a hypermetropic eye ought *not* to have distinct vision for distant objects, yet we often find on testing a patient that his vision appears to be normal, *i. e.* that he can read the Test Type No. 6 Snellen at 6 metres, and yet he is the subject of hypermetropia.

How comes it then that this hypermetropic eye, in which vision for distant objects on theoretical grounds should be indistinct, appears to have normal distant vision ?

The patient has been exercising his accommodation (Fig. 18).

In the emmetropic eye accommodation is used only for the purpose of focussing the diverging rays from a *near* object, but in this hypermetropic eye it has been used for focussing the parallel rays from a *distant* object.

72. In order to test this statement we place the patient at a distance of 6 metres from the test types, and we find his vision = $\frac{5}{8}$, *i. e.* is apparently normal for distant objects. We then place before his eyes say a + 0.5 D.

His vision, we will suppose, is still $\frac{5}{8}$.

We then continue to place before the eye + lenses of gradually increasing power, till we come to a lens with which the patient can no longer see $\frac{5}{8}$.

We then revert to the highest lens with which the vision was still $\frac{5}{8}$, and this lens is a measure of the *manifest* hypermetropia.

73. Supposing this lens to be a lens of + 2.5 D., then the patient has 2.5 dioptries of *manifest* hypermetropia or H. m., as it is usually written.

We have thus far learned that the eye under consideration is not an emmetropic eye which focusses on the retina parallel rays from a distant object. For if it were an emmetropic eye, these + lenses should have so increased the refraction of the rays that they would have been focussed in front of the retina—causing indistinct vision.

74. We will now paralyse the patient's accommodation by means of atropine, and on applying test lenses we find as the result of the paralysis of his accommodation that now he has distinct vision for distant

objects, even though say a + 4 D. lens is given him, *i. e.* his 2.5 D. of *manifest* hypermetropia are now increased to + 4 D. of *total* hypermetropia.

The paralysis of accommodation has disclosed 1.5 dioptries of hypermetropia which were previously not manifest.

75. Such hypermetropia is called *latent* hypermetropia, or H. l.

Hence the total hypermetropia of any eye always = H. m. + H. l. (manifest hypermetropia + latent hypermetropia = Total hypermetropia).

76. The latent hypermetropia is the result of a tonic spasm of the ciliary muscle, and arises in consequence of the accommodation of the eye being constantly used for the purpose of obtaining distinct vision for distant objects; hence the ciliary muscle is always in a state of tension.

77. Supposing that we consider an eye with a total hypermetropia of 6 dioptries, such an eye would require to exercise 6 D. of accommodation in order to focus on the retina the parallel rays from a distant object, *i. e.* it would only have distinct *distant* vision at the cost of the consumption of 6 D. of accommodation.

78. Now, accommodation is intended to be used for the purpose of giving distinct vision for *near* objects, and not for the purpose of distant vision.

79. How then will this irregular consumption of his accommodation affect this hypermetrope's near vision?

Clearly if 6 D. of accommodation are spent in

securing distant vision, his accommodation which is left for near objects is less by that amount which he has used for distant vision, *i. e.* in this case 6 D.

And supposing the hypermetrope to be thirty years of age, at which age there is usually only about 6 D. of accommodation, then this hypermetrope would have no accommodation at all remaining for near vision, and would simply have clear distant vision.

80. Hence the effect of hypermetropia on near vision depends not only on the amount of hypermetropia, but also upon the amount of accommodation which the patient has remaining according to his period of life.

81. But the amount of accommodation varies with age, for at

10 years	the accommodation remaining is	14 D.
20	„ „ „	10 D.
30	„ „ „	7 D.

It is clear, therefore, that if the hypermetropia be moderate in amount and the patient young, *i. e.* with a great amplitude of accommodation, then the hypermetropia will be of little inconvenience, as the patient by reason of his youth would be the possessor of such an amount of accommodation that he can afford to spend some in correcting his hypermetropia (*i. e.* for distant objects) and still have sufficient remaining to spend in securing distinct near vision.

Thus suppose we have + 3 D. of hypermetropia in a child ten years of age with 14 D. of accommodation. It is clear that he would have 11 D. of accommodation (14 D. — 3 D.) for near vision. So he would have enough accommodation and some to spare. For 11 D.

of accommodation would place his near point at 9 cm. ($\frac{100}{11} = 9$ cm.).

But when he has arrived at thirty years of age his accommodation will naturally have decreased to 7 D. (81) and in this case, allowing + 3 D. for his hypermetropia, he can only have 4 D. of accommodation remaining, *i. e.* his near point will have receded to 25 cm.

In fact he will have become presbyopic at thirty years of age, since presbyopia is considered to commence when the near point has receded beyond a distance of 22 cm. from the eye.

82. But in making the calculations which we have done in the preceding paragraph (81) we have assumed that these hypermetropes have used *all* their accommodation, but it must be borne in mind that the habitual use by any eye of the whole of its possible accommodation may be attended with very evil consequences.

83. So that for the comfortable use of sustained accommodation at any distance, the eye must always have a portion of its accommodation unused, *i. e.* in reserve; such reserved accommodation is only to be used on special occasions and for short periods, and consequently if in the case cited (81) we allow for the accommodation which is required to be held in reserve, this boy of ten years of age with 3 D. of hypermetropia may have at his command, for sustained vision, only say 8 D. of accommodation instead of 11 D., and by the time that he is thirty years old there may be none at all remaining for near vision, after his 3 D. of hypermetropia has been provided for.

84. Therefore even in cases of hypermetropia of low degree the error had better be corrected, in order to avoid the consequences which may follow on the use of the whole of the accommodation which the eye is capable of exercising, and although in these cases nothing may occur to draw the patient's attention to any error in his sight, for so long as his accommodation continues vigorous it may suffice for giving him a distinct vision for both distant and near objects, yet when anything occurs to diminish the vigour of such accommodation, as ill-health or increasing years, with its natural failure of accommodation, then the balance of the patient's accommodation left over after the focussing of distant objects had been provided for, and which formerly sufficed also for focussing near objects, is now no longer sufficient for that purpose; and a person who up to the time of the occurrence of an illness had not noticed any failure of sight, is now often unable to see near objects distinctly.

The illness, by weakening the power of the over-acting ciliary muscle, has revealed the existence of the hypermetropia.

85. At first sight the correction of hypermetropia would seem to be comparatively easy, viz. to give the highest + lens which corrects the total hypermetropia, thus converting the eye into an emmetropic eye—with distinct distant vision, without any accommodation—and if a near object is required to be viewed, then by bringing the vigorous and hypertrophied ciliary muscle into play, the diverging rays

from the object would then be duly focussed on the retina by the aid of the resulting accommodation.

But in practice, except in cases of young persons with slight hypermetropia and vigorous accommodation, it is found best not to correct the whole of the total hypermetropia, but to order such lenses as will not correct quite all of it, and thus leave the eye to make a partial use of its accommodation.

86. The experience of ophthalmic surgeons prompts them to adopt somewhat varying rules, but the following will probably lead to satisfactory results :

(1) Ascertain the amount of manifest hypermetropia and add 1 D. as representing the latent hypermetropia ; or, better—

(2) Ascertain the amount both of manifest and latent hypermetropia, and then we may follow the rule laid down by Donders.—

“ That we should prescribe such glasses as correct the whole of the H. m. and one fourth of the H. l.”
(*Hartridge.*)

CHAPTER VI

PRESBYOPIA

87. Presbyopia is considered by many ophthalmic surgeons as commencing whenever the near point of distinct vision has receded beyond a distance of 22 cm. from the eye.

88. This being quite an arbitrary standard, a more scientific statement would be to say that presbyopia commences whenever the near point of distinct vision recedes beyond the most convenient working distance. And in this case it is evident that its commencement will vary according to the occupation as well as with the age of the patient. For correcting presbyopia on this basis see **106**. Inasmuch then as the arbitrary fixed standard for the commencement of presbyopia (22 cm.) has the merit of simplicity, and also renders a clear description of presbyopia more easy, we shall base our remarks on the supposition that presbyopia commences when the near point of vision has receded beyond 22 cm. from the eye, but we shall also give directions for its calculation and correction on the basis of its varying with the occupation and age of the patient (**96**).

In presbyopia, then, the near point recedes further and further from the eye in consequence of a gradual

decline in the power of accommodation—a decline which is the result of a decrease in the elasticity of the lens, accompanied probably by a diminution in the power of the ciliary muscle, and as accommodation mainly consists in an increase in the curvature of the lens, induced by the action of the ciliary muscle, it follows therefore that by reason of increase of age, not only is the lens, on account of its increasing firmness, less capable of responding to calls made on it to increase its curvature, but also that the ciliary muscle is less potent for calling such increased curvature into play.

Hence the power of accommodation must necessarily decrease with advancing years.

This gradual decline in the power of accommodation is supposed to commence at the age of ten years, at which age the eye possesses 14 D. of accommodation; at the age of twenty it has declined to 10 D., an amount of accommodation which would place the near point at 10 cm. from the eye, because $\frac{100}{10 \text{ D.}} = 10 \text{ cm.}$

At forty years of age the eye has only 4.5 D. of accommodation left, which would place the near point at 22 cm., because $\frac{100}{4.5} = 22 \text{ cm.}$

89. At forty years of age then the eye has arrived at the starting-point of presbyopia, as the power of its accommodation has declined to 4.5 D., and consequently the near point has receded to 22 cm. $\frac{100}{4.5} = 22 \text{ cm.}$

90. At about sixty-five years there is no power of accommodation at all remaining, and a patient of that age will require a $+ 4.5$ D. lens in order to replace that loss of accommodation which has taken place since he was forty years old.

91. Thus in an emmetropic eye presbyopia may be said to consist in a gradual loss, between the ages of forty years and sixty-five years, of 4.5 D. of accommodation.

92. This disappearance of the 4.5 D. of accommodation has taken place at a regularly graduated pace, for 1 D. disappears with every five years added to the age of forty.

The oculist therefore has to dole out to his patient 1 D. of accommodation every five years, and he does this by placing *outside* the eye that amount of accommodation which has been lost, so to say, from the inside of the eye.

In fact, he supplies the missing accommodation in the shape of that $+$ lens which will exactly equal the amount of the missing accommodation, every 1 D. lost being efficiently replaced by a $+ 1$ D. lens.

93. At forty-five years there has been lost $+ 1$ D. of accommodation, therefore a $+ 1$ D. lens will be required outside the eye to replace the 1 D. which has been lost.

At fifty years there have been lost $+ 2$ D. of accommodation, and therefore a $+ 2$ D. lens will be required outside the eye to replace the $+ 2$ D. which has been lost.

At fifty-five years there have been lost $+ 3$ D., and

therefore a + 3 D. lens will be required to replace it.

At sixty years there have been lost + 4 D., and therefore a + 4 D. lens will be required to replace it.

At sixty-five years (about) all accommodation has disappeared, and therefore a + 4.5 D. lens will be required to replace it.

Such a patient at sixty-five years of age, having lost all accommodation, will have no point of near vision, though his distant vision may remain perfect.

94. Sometimes, however, distant vision becomes impaired by age chiefly in consequence of the lens becoming less convex, in which case the eyes may not be capable of focussing, as they used to do, the parallel rays from a distance; such rays would consequently be focussed behind the retina as in hypermetropia, and the patient is then said to have a species of hypermetropia which is known as *acquired* hypermetropia.

95. In all the instances given in (93) it will be seen that in an ordinary case of presbyopia a simple subtraction sum has to be done if we wish to supply the proper correcting lens.

(A) Find out that lens whose focal distance is the required near point, *e. g.* if the required near point of vision is 22 cm., then the lens required is + 4.5 D.

$$\left(\frac{100}{22} = 4.5 \text{ D.} \right).$$

(B) From that lens subtract the amount of accommodation which remains for the age of the patient under consideration.

Say the age is fifty-five years. At that age the accommodation remaining is + 1·5 D., for, since the age of forty, when he had remaining 4·5 D. of accommodation, he has passed through three spaces of five years each, and during each space he has lost + 1 D. of accommodation. Hence his total loss is + 3 D., and if 3 D. be subtracted from 4·5 D., he therefore has remaining 1·5 D. of accommodation, or, to put it in figures,—

Lens representing required near point . .	4·5
Accommodation lost since forty years . .	3

Accommodation remaining at fifty-five years + 1·5 D.

(c) Then having found the accommodation remaining, subtract (B) from (A).

Thus at fifty-five years

Required near point (A)	4·5
Accommodation remaining at fifty-five years (B)	1·5

Lens required + 3 D.

96. It must be remembered, however, that for special occupations the near point may be required to be at some other distance than 22 cm., and then the terms of the sum will have to be varied accordingly.

Suppose the near point is required to be at 40 cm. instead of 22 cm.

Then $\frac{100}{40} = 2·5$ D.

Therefore with a patient of fifty-five years our sum will be varied as follows :

Lens representing required near point . . .	2.5 D.
Accommodation remaining at fifty-five years	1.5

Lens required	+1 D.
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But in all cases it is in practice found best to give a lens a little below the fully correcting power as found by the above method.

To repeat—an emmetropic eye is one which in a state of rest (*i. e.* exercising no accommodation) has distinct vision for the parallel rays from distant objects, but such an eye, by bringing into play its power of accommodation, is able also to have distinct vision for the diverging rays from a near object.

Hence such an eye has a distant point of distinct vision and also a near point of distinct vision.

But as age advances there is a gradual diminution in the extent of this accommodating power of the eye, the result of which is that as years go by the near point of distinct vision recedes further and further from the eye in proportion to the decrease of the power of accommodation, and the same type which at a distance of 22 cm. could be read distinctly by a person of forty years of age, would, when the reader is fifty years old, have to be held at a distance of 40 cm., in order to be seen as clearly as it was seen ten years previously. Such a condition of things is called presbyopia.

Of course if the size of the type is gradually increased according to the gradual disappearance of the accommodation, it could still be read at 22 cm. And this is what most presbyopics do.

In order to delay taking to the use of spectacles, they take to using large print, rejecting the smaller type, till it becomes rather difficult to supply them with the type which they like, and then they are driven as it were to spectacles, which practically make their small type into large type.

The explanation of this necessity for moving the type further and further from the eye as age advances, is that the further the type is from the eye the less divergent are the rays proceeding from it to the eye, and since they are less divergent, less accommodation of the eye is called for in order to focus such rays on the retina.

This is just what such an eye requires in advancing years, because it possesses less and less power of accommodation.

Thus presbyopic persons meet their loss of the power of accommodation by making less demand on that power, or, in other words, by moving the type further off, they supply to the eye rays of just such an amount of divergence as they know by experience that their eye can focus on the retina.

97. Inasmuch as in presbyopia the near point gradually recedes by time-regulated stages it follows that if the rate of decrease of accommodation is known, as well as the patient's age, we can also know what is the amount of his presbyopia (assuming of course that it commences at 22 cm.) or if his presbyopia is known, his age can be approximately fixed.

98. But the above statements only apply of course to the emmetropic eye, for it is clear that presbyopia

will be considerably modified both as to the time of its commencement and the rate of its progress, according as the eye was originally myopic or hypermetropic.

99. In hypermetropia, for instance, suppose there is + 2 D. of hypermetropia.

That will clearly mean that + 2 D. of accommodation has been consumed by the eye, in order to focus *distant* objects.

It follows then that during all the time which the hypermetropia has existed, the eye has had + 2 D. less of accommodation for *near* objects than has an emmetropic eye of the same age—or in other words, the accommodation for near objects is less *by* the amount which has been expended on distant objects, viz. + 2 D.

And if the emmetropic eye at the age of forty years has + 4·5 D. of accommodation remaining, and therefore placing its near point at 22 cm. $\left(\frac{100}{4\cdot5 \text{ D.}} = 22 \text{ cm.}\right)$; it follows that at the same age the eye with + 2 D. of hypermetropia will only have 2·5 D. of accommodation *remaining* for near objects, instead of the 4·5 D. which it ought to have, because, although its total amount of accommodation is not less than in an emmetropic eye of the same age, it has applied its accommodation differently, part having been applied to distant objects, whereas the whole of it ought to have been expended on focussing near objects.

Consequently at forty years of age this eye with + 2 D. of hypermetropia has only 2·5 D. of accommodation remaining which it can apply to a near

object, and its near point will therefore be at 40 cm. $\left(\frac{100 \text{ cm.}}{2.5 \text{ D.}} = 40 \text{ cm.}\right)$, whereas an emmetropic eye of the same age, with its 4.5 D. of accommodation, would have its near point at 22 cm. $\left(\frac{100 \text{ cm.}}{4.5 \text{ D.}} = 22 \text{ cm.}\right)$.

So that if presbyopia is considered as commencing when the near point is beyond 22 cm., then this patient with + 2 D. of hypermetropia has really been presbyopic for some time previously to attaining forty years of age, whereas at forty years the emmetropic eye is only just beginning to assume presbyopia.

100. Hence we find that in hypermetropic eyes presbyopia *must* commence at a much earlier age than it does in emmetropic eyes.

101. Therefore, in making our calculations for presbyopia occurring in a hypermetropic eye, it is evident that we must make due allowance for the hypermetropia, and this can be done (1) by correcting the hypermetropia, *i. e.* by converting the hypermetrope into an emmetrope; and then (2) by treating his presbyopia as we should treat it (95) if there was no hypermetropia existing, which is equivalent to saying we must *add* to the lens which represents the hypermetropia that lens which would suit an emmetrope with presbyopia.

Thus in the case we have considered of hypermetropia + 2 D. in a patient fifty-five years the lens required would be + 5 D. instead of + 3 D. which would be required if his eye were emmetropic. The calculation would be :

Lens representing near point required . . . 4.5 D.
 Accommodation remaining at fifty-five years 1.5

Lens required for an emmetrope +3 D.
 Add on + 2 D. hypermetropia 2 D.

Lens required allowing for the + 2 D. of
 hypermetropia + 5 D.

102. In the myopic eye everything is the reverse, so to say, of the hypermetropic eye. Suppose we have to deal with a case of -4.5 D. of myopia.

That means that the patient's *far* point of distinct vision is 22 cm. $\left(\frac{100}{4.5 \text{ D.}} = 22 \text{ cm.}\right)$. Therefore he requires to exercise no accommodation in order to see at 22 cm.

Hence the total loss of his accommodation can never make any difference to him, for he will always be able to see distinctly at 22 cm., which is his *far* point, therefore he can never become presbyopic.

Of course if the myopia is of a higher degree than -4.5 D. it is still more impossible for him ever to become presbyopic.

A patient therefore with -4.5 D. or more of myopia can never become presbyopic, and in cases of myopia of less than -4.5 D. the date of the commencement of presbyopia is necessarily postponed—in comparison with the date of its commencement in emmetropes.

For just as myopia is the reverse of hypermetropia, and as the hypermetrope, when wishing to use his

accommodation for near vision, starts at a disadvantage in comparison with an emmetrope, because his far point from which he starts is *beyond* infinity, *i. e.* six metres; so, on the contrary, the myope, in comparison with an emmetrope, starts for the near point with an advantage, because the *far* point from which he starts is nearer than infinity—how much nearer will depend on the amount of his myopia.

103. As the *disadvantage* of the hypermetrope, in connection with presbyopia, is measured by the amount of his hypermetropia, so the *advantage* of the myope is also measured by the amount of his myopia.

A myopic eye, therefore, before it could be the subject of presbyopia, must lose, in the run for the near point, all the advantage which its myopia gave it, and as this advantage is measured by the amount of the myopia, it follows that in remedying presbyopia in a myopic eye we must do exactly the reverse of what we did in hypermetropia.

In the hypermetropic patient, by first correcting his hypermetropia, before proceeding to deal with his presbyopia, we virtually deprived him of the *disadvantage*, in connection with the near point, which his hypermetropia gave him, his far point having been *beyond* infinity, of course.

Similarly, in a case of presbyopia occurring in a myope, we proceed to deprive him of the *advantage* in connection with the near point which his myopia gives him; that is, we first correct his myopia and then treat his presbyopia as we should do if he was an emmetrope.

This is equivalent to saying that we must *subtract* that lens which represents his myopia from the lens which would suit an emmetrope of the same age.

Therefore, in a case of myopia — 2 D. in a person aged fifty-five years, we should work as follows :

Near point required 4.5 D.

Accommodation remaining at fifty-five years 1.5

Lens required if there was no myopia . . . + 3 D.

Subtract the amount of myopia . . . - 2 D.

Lens required + 1 D.

or, which amounts to the same thing, correct the myopia by — 2 D. lens; then correct the presbyopia + 3 D., and + 3 D. — 2 D. = + 1 D.

104. It follows, from what has been said above, that as the hypermetrope has a disadvantage and the myope an advantage in connection with presbyopia, so in hypermetropia we have presbyopia commencing early, and in myopia its advent is delayed, the variation in each case depending on the amount of the error of the refraction.

Hence the origin of the popular idea that short-sighted persons are also strong sighted, by which is meant that they are longer in showing the result of the failure of their accommodation.

105. Table of amount of presbyopia in an emmetropic eye :

Age.		Distance of near vision. cm		Lens required to bring near points to 25 cm.
40	...	22	...	+ 0
45	...	28	...	+ 1 D.
50	...	43	...	+ 2 D.
55	...	67	...	+ 3 D.
60	...	200	...	+ 4 D.
65	...	Infinity	...	+ 4.5 D.

106. If we prefer to regard presbyopia, not as commencing when the near point has receded beyond a given fixed unvarying distance, but as presenting itself whenever the near point has receded to an inconvenient distance, and this, as said before, is a more scientific view to take of it, then the method for its correction will vary somewhat from that previously described.

The first thing to do is to find out at what distance from the eye the near point is in any given case.

The near point, or punctum proximum, is that point at which Snellen's No. 5 Type and Jaeger's No. 1 Type can be clearly read. We will suppose then that the near point is at a distance of 50 cm. from the eye, and that the patient requires to be able to read at a distance of 25 cm.

Now, it is clear that what we have to do is to bring the near point from 50 cm. distant to a point 25 cm. distant.

It is equally clear that to bring the near point from infinity to 50 cm. involved the exercise of 2 D. of accommodation, because $\frac{100}{50} = 2$ D.

It is equally clear that to bring the near point from infinity to 25 cm. would involve the exercise of 4 D. of accommodation, because $\frac{100}{25} = 4$ D.

Therefore if we increase the accommodation by the amount which it fell short of in its effort to bring the near point to 25 cm., we shall have accomplished the desired end, and shall have remedied the presbyopia.

Hence the difference between the patient's actual near point and his desired near point will measure the deficiency of his accommodation, and therefore in the above case as

25 cm. = 4 D. of accommodation, and

50 cm. = 2 D. of accommodation,

therefore + 2 D. of accommodation is the difference between the actual near point and the one desired, and a + 2 D. lens would bring the near point to 25 cm.

It is evident that there is a much greater amount of elasticity about this system of correcting presbyopia as compared with its fixed definition as commencing at 22 cm., since it is capable of being varied to suit every kind of requirement.

For the difference between the two points being found, that difference accurately represents the accommodation which has been lost, and which it is required to replace.

Any existing hypermetropia or myopia must of course be corrected previously to finding out the near point, and will have to be allowed for when calculating

the lens required, just as was done under the fixed 22 cm. method, viz. by adding the lens which corrects the hypermetropia and subtracting that which represents the myopia.

CHAPTER VII

ACUTENESS OF VISION

107. In order to compare the vision of one person with that of another, or to be able to note the exact amount of improved vision which any patient receives at our hands, it is necessary that we should have a generally accepted standard of vision. Such a standard would then be regarded as the standard of normal vision.

108. The standard, then, of normal vision which is generally accepted is that a normal eye should see clearly any object which subtends an angle of 5 minutes, *i. e.* which subtends the visual angle.

And, taken in connection with the test types generally used, what is meant by a statement that the object to be seen by the normal eye must subtend an angle of 5 minutes?

109. Before answering this question we must understand what the visual angle means:

It is well known that the retina receives on its surface an impression of an inverted image of any object which is focussed on it, *i. e.* the axial rays from an object cross and are refracted by the surface of the cornea, the front surface of the lens, and the front

surface of the vitreous, so that they cross one another at the point N , Fig. 19, which is called the nodal point, and then form the inverted image on the retina.

The angle at N is called the visual angle and is an angle of 5 minutes.

It is evident that if DO , Fig. 19, be an object situated at a distance of 6 metres from the nodal point N of the eye, which is emmetropic, it would form an impression $O'D$ on the retina. And if the angle at N is an angle of 5 minutes, then an object of the size of DO subtends an angle of 5 minutes, and if it be removed still further off to

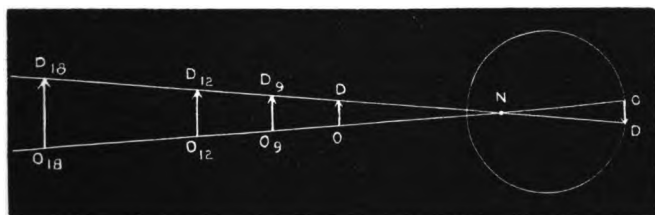
$D_9 O_9$ at a distance of 9 metres, or to

$D_{12} O_{12}$ „ „ 12 metres, or to

$D_{18} O_{18}$ „ „ 18 metres,

and at the same time were to become increased in size (as in Fig. 19) in proportion to its increased

FIG. 19.



distance from N , it will in each case still continue to subtend an angle of 5 minutes.

110. Hence, if DO were a letter in the test type and of such a size as would subtend an angle of 5 minutes at N , it will be focussed on the retina with distinct

vision if the eye is emmetropic, and would be known as No. 6 type, and we should state that the vision was normal by the formula that

$$V. = \frac{6 \text{ metres (or distance at which the type is)}}{6 \text{ type: read divided by the number of}} \\ = 1. \quad \text{the type)}$$

Or, in the same way, we should say of a smaller letter that vision was normal because

$$V. = \frac{5 \text{ metres}}{5 \text{ type.}} \\ = 1.$$

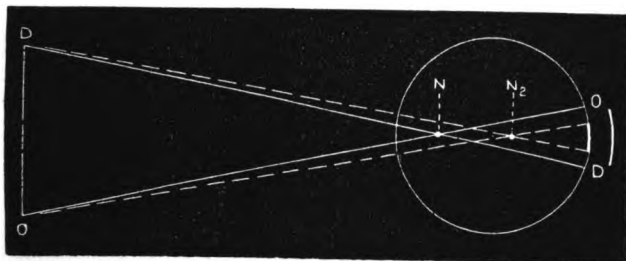
And so on for still smaller letters at decreasing distances. But it is not safe to rely upon this test at less than 3 metres distance, because the accommodation of the eye may be brought into play in reading the types at shorter distances.

The test types usually employed are Snellen's. They of course should be exposed to a good light when we are testing acuteness of vision, and in anything like a prolonged period of testing we ought to have a duplicate set of letters on the reverse side of the board, as patients are often very quick at learning their letters.

111. It will be evident then that in any given eye the exact position of the nodal point *N* is of great importance as regards the refraction power of that eye; and that if from any circumstances the position of the nodal point should be shifted either nearer to or further from the cornea, that very great consequences will result from such a shifting. We will only take notice of the following.

112. In Fig. 20 let N represent the nodal point in a myopic eye, a point placed nearer to the cornea than

FIG. 20.



N . = Nodal point in myopic eye.

N_2 . = Nodal point in hypermetropic eye. The nodal point in an emmetropic eye would be situated somewhere between N and N_2 .

it is in an emmetropic eye, and let N_2 be the nodal point of a hypermetropic eye, placed further away from the cornea than it is in an emmetropic eye.

It is clear that the angle at N in the myopic eye will be a larger angle than is the angle at N_2 in the hypermetropic eye.

113. Hence in the myopic eye, with its anterior nodal point, the object $D O$ will form a larger image $O D$ on the retina than it does in the case of the hypermetropic eye with its posterior nodal point. (The image of the hypermetropic eye is represented by the dotted line.)

In an emmetropic eye the nodal point would be situated somewhere between the points N and N_2 , and hence its image on the retina would be intermediate

in size between that of the myopic and hypermetropic eye.

114. Hence the correctness of the statement that myopic eyes have larger impressions of a given object than the emmetropic or hypermetropic eye has ; and this is shown practically, for it is a matter of frequent observation that a short-sighted person is what is popularly called a strong-sighted person, that is to say, if we start an emmetrope and a myope to look for a small object dropped on the carpet, the chances are that the myope will find it first, because the larger image of the object which he receives on his retina gives him an advantage.

115. It is well known that biconvex lenses enlarge and biconcave lenses diminish the images received on the retina. This somewhat follows from what we have written as regards the size of the images in hypermetropia and myopia (113) (114).

It will be seen clearly, therefore, if the nodal point is by any means brought forwards (compared with the position of it in the emmetropic eye), it necessarily follows that we have placed the nodal point in the same forward position which it occupies in myopia, and hence that the visual angle at N will have been made larger, and therefore (112) that the image on the retina has become enlarged.

A convex lens, by giving convergence to the rays before they meet the cornea, will of necessity bring forward the nodal point and so give us an enlarged image on our retina.

Hence the $+$ lens has magnified the image for us.

116. It follows, therefore, that a concave lens does the reverse of a convex lens, and therefore a — lens in front of the eye will displace the nodal point further back from the cornea and thus *diminish* the visual angle α .

Hence, the image received on the retina will be diminished in size.

117. This fact of the smallness of the image which we receive when looking through — lenses explains one of the reasons why, when fitting myopic patients with — lenses, we do not always give them the fully correcting lens.

Such a lens would often so diminish the size of the letters of a book that the patient, in order to enlarge the size of the image on his retina, will perhaps bring the book close up to his eyes. Thus, a too powerful — lens will, in this case, have created over again the very mischief for the correction of which it was originally supplied.

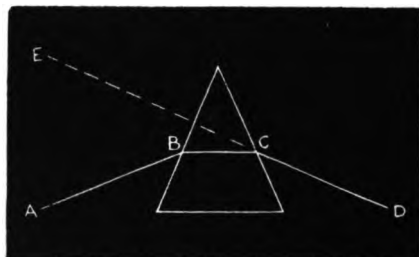
CHAPTER VIII

PRISMS AND CYLINDRICAL LENSES

118. Rays of light when passed through a prism are refracted towards the thickest part of the prism.

Thus in Fig. 21 a ray of light AB meeting the sur-

FIG. 21.

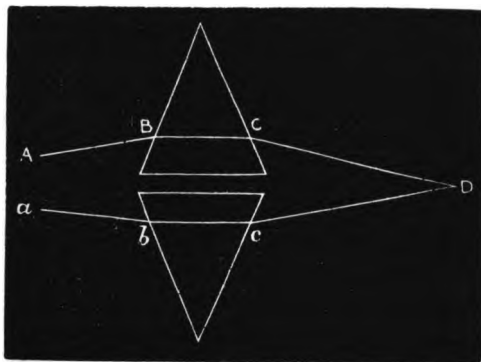


face of the prism at B will then be refracted to the position of BC , and at C again it will be refracted in the direction of CD , and though the ray proceeded from A , yet an observer at D would refer such a ray to the point E , i.e. to a point representing DC prolonged.

119. If we place two prisms together so that their bases are adjacent we practically manufacture a con-

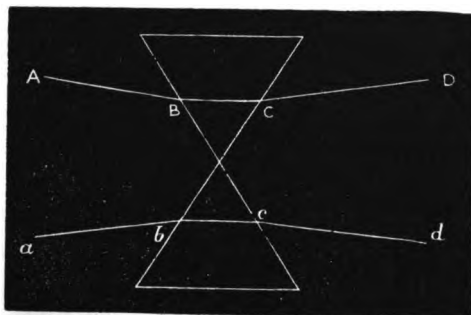
vex lens as in Fig. 22, when the rays from Aa will be focussed at D .

FIG. 22.



120. Similarly if we reverse the position of the prisms, placing their bases upwards so that their apices

FIG. 23.



are adjacent, Fig. 23, we practically manufacture a concave lens; for as each prism refracts the rays

towards its base, *i. e.* towards the thickest part, the two when placed with their apices adjacent will cause the rays of light to diverge as if they had passed through a concave lens.

We have thus far considered + and - spherical lenses; and for the purposes of this book we need only to take cognisance of three kinds, *viz.* :

(1) + spheres or biconvex lenses, *i. e.* with both surfaces convex.

(2) - spheres or biconcave lenses, *i. e.* with both surfaces concave.

(3) Cylindrical lenses, convex and concave.

If we hold a spherical biconvex lens vertically in front of our eye, and at the level of it, we may consider the lens as having (1) an upper or north point;

FIG. 24.



Biconvex or + lens.

FIG. 25.



Biconcave or - lens.

(2) a lower or south point; (3) an east point; and (4) a west point; and if we move our finger vertically from north to south over its distant surface we note that this vertical meridian is curved or convex; and if we move our finger from east to west horizontally over the same surface we find that its horizontal

meridian is also curved or convex. And however much we rotate the lens in our fingers we always have a north and south convex vertical meridian, and also an east and west convex horizontal meridian.

These two meridians, called respectively the vertical and horizontal meridians, are thus at right angles to each other and present exactly equal amounts of curvature.

If we regard this lens as representing the convex cornea then we may consider the cornea also as having vertical and horizontal meridians, each convex to the same extent.

121. If in the cornea these two meridians are not *equally* curved, then we have that error of refraction which is called astigmatism, see (127, 128, 129).

What has been said above (120) in relation to a convex lens applies equally to a concave lens.

122. A cylindrical lens differs from a spherical lens in the fact that it has only *one* of its meridians curved.

Cylindrical lenses are spoken of as having an axis, the meaning of which will be explained further on.

In order to form an idea of a cylindrical lens we will take a round cedar pencil, then split it in halves where the halves are glued together; we will then cut off from one half of the pencil a piece one inch in length.

If we hold this piece of pencil one inch long in front of our eyes so that the glued flat surface is towards the face, and the curved surface turned away from the face, and if we hold it with the long axis (one inch) vertically, then the curved surface may be

considered as having a north and south vertical meridian one inch in length, and also an east and west horizontal meridian equal to half the circumference of the original pencil.

But only one of the meridians of this piece of pencil (or cylindrical + lens as it really is in shape) is curved.

Which of the two meridians will be the curved one will entirely depend on the direction of the axis (one inch long) of the pencil or cylindrical lens.

(A) For if, when the long axis is held vertically with the glued surface towards our face, we pass our finger over the distant surface from north to south, or over the vertical meridian, we shall pass it over a plane surface; and hence the vertical meridian (corresponding with the direction of the axis of the lens) is plane, not convex.

(B) But if we now pass the finger over the distant surface from east to west, that is over the horizontal meridian, we shall have passed it over a convex surface, corresponding to half the circumference of the original whole pencil.

123. Thus with the axis of this cylindrical + lens held *vertically*—

(A) The *vertical* meridian is plane *non-refracting*.

(B) The horizontal meridian is convex and *refracting*.

Suppose now we hold the long axis of the lens *horizontally*, then—

(A) The *horizontal* meridian is plane *non-refracting*.

(B) The vertical meridian is now the convex and refracting one.

124. Hence this cylindrical lens can be made to fulfil two different purposes according as the axis is placed vertically or horizontally; and the point to remember is that, whichever way it is placed, the direction of the axis represents the direction of the plane non-refracting meridian; and consequently, the meridian which is at right angles to the direction of the axis always represents the refracting meridian.

Hence the necessity for some mark on cylindrical lenses whereby we may know the direction of their axes. In many boxes of trial lenses the axis or direction of the non-refracting meridian is indicated by the direction of a strip of ground glass on the margin of the lens.

The use of cylindrical lenses is to correct errors in the refraction of *one* of the meridians of the cornea in astigmatism.

125. For instance, one form of astigmatism, simple hypermetropic astigmatism, presents a cornea with a vertical meridian of *normal* refraction, and therefore the refraction of that vertical meridian does not require to be interfered with.

But the horizontal meridian of such an eye may be hypermetropic say to the extent of 2 D., and this horizontal meridian requires a +2 D. lens to bring back on to the retina the focus of the horizontal meridian, and at the same time we must not interfere with the vertical meridian, which is normal.

The remedy for this state of things will be clearly

a +2 D. *cylindrical* lens, placed with its axis (*i. e.* its non-refracting meridian) vertical.

With the cylindrical lens in that position the vertical meridian of the cornea is unaltered, whilst the horizontal meridian is supplied with increased refracting power to the extent of +2 D.

Had we used a +2 D. *spherical* lens we should have altered the refraction of both vertical and horizontal meridians of the cornea and have done no good; because at the same time that the sphere was correcting the faulty horizontal meridian of the cornea, it would necessarily create an error in that vertical meridian of the cornea which had previously been an emmetropic meridian; and thus we should have changed a faulty horizontal meridian into a faulty vertical one.

All the above remarks touching cylindrical plus lenses of course apply equally to cylindrical minus lenses; and the main point to remember is :

(1) If the axis is vertical, the horizontal meridian is refracting.

(2) If the axis is horizontal, the vertical meridian is refracting.

126. Cylindrical lenses are numbered in the same way as spherical lenses, according to the refracting power of their one refracting meridian.

Thus cylindrical lenses of +1 D., +2 D., +3 D., &c., or -1 D., -2 D., -3 D., &c., would mean that the one refracting meridian which they possess, whether it was convex or concave, is of the power of a spherical lens of 1, 2, 3, &c., dioptries.

CHAPTER IX

ASTIGMATISM

127. When we say that an eye is the subject of astigmatism we mean that the vertical and the horizontal meridians of that eye refract unequally.

This error of refraction may exist :

(A) In one meridian only.

(B) In both meridians.

128. When only one meridian has faulty refraction, the other meridian being emmetropic, we then have a case of simple astigmatism.

129. When both meridians have faulty refraction we then have either :

(A) Compound astigmatism or

(B) Mixed astigmatism.

130. It will help us towards gathering a good idea of the different forms of astigmatism if we take it as a fact :

(A) That the vertical meridian of the cornea is naturally more convex than is the horizontal meridian, and therefore :

(B) In all the forms of astigmatism the focus of those rays which are refracted by the vertical meridian

is always more anterior (*i. e.* nearer to the cornea) than is the focus of those rays which are refracted by the horizontal meridian (*vide* 131).

Let us cut in halves lengthwise an ordinary shaped pear, *i. e.* one whose length is greater than its breadth. Then let us hold one half in front of our eyes, with the long axis horizontal : the cut flat surface towards us, and the round surface turned away from us.

Then we may think of the round surface of the pear as giving us roughly the shape of the meridians of the cornea.

For if we pass one finger downwards over the round front surface of the pear (*i. e.* from north to south as it were) we shall pass it over the vertical and *more* convex meridian of the pear (or cornea) ; and if we pass the finger horizontally from one end of the pear to the other (*i. e.* from east to west as it were) we shall pass it over the horizontal and *less* convex meridian of the pear (or cornea).

This increased convexity of the vertical meridian will help us to understand why in most of the various kinds of astigmatism the focus of those rays which are refracted by the vertical meridian is nearer to the cornea than is the focus of those rays which are refracted by the horizontal meridian.

131. It is not absolutely correct to say that in *all* cases of astigmatism the vertical rays are focussed in front of the point at which the horizontal rays come to a focus, for the reverse of this is sometimes the case, but by accepting the statement that the vertical meridian is the most convex and therefore has its

focus, more anterior than is the focus of the horizontal meridian, we are able more easily to get a fixed idea of the varying errors in the several kinds of astigmatism.

So that while we remember the comparison of the curves of the meridians of the pear when lying, as it usually does, on its side, thus presenting a more convex vertical meridian, yet we must also remember that a pear *can* be placed so as to rest upon its end, in which position its vertical meridian will no longer be the most convex.

In applying this to astigmatism we argue that just as a pear *usually* lies on its side with its vertical meridian most convex, so in cases of astigmatism do we usually find that the vertical meridian of the cornea is the most convex, and therefore has its focus anterior to the focus of the horizontal meridian; but that, inasmuch as a pear *can* stand on its end, and in this position would have its horizontal meridian most convex, so also an astigmatic eye may also have its horizontal meridian most convex, with the necessary result that in this case the focus of the horizontal rays would be anterior to the focus of the vertical rays.

132. There are then five varieties of astigmatism :

- (1) Simple myopic astigmatism.
- (2) Simple hypermetropic astigmatism.
- (3) Compound myopic astigmatism.
- (4) Compound hypermetropic astigmatism.
- (5) Mixed astigmatism.

133. In simple astigmatism, whether simple myopic

or simple hypermetropic, only one meridian has an error of its refraction.

134. In compound astigmatism, whether compound myopic or compound hypermetropic, both meridians have errors :

(A) Either both are myopic, but in different degrees, then we have compound myopic astigmatism.

(B) Both being hypermetropic, but in different degrees, then we have compound hypermetropic astigmatism.

135. In mixed astigmatism both meridians have errors of refraction, one meridian being myopic and the other being hypermetropic.

We will at present discuss only the simple forms of astigmatism; and we will assume that for their diagnosis and treatment we only use the usual trial lenses with the astigmatic clock and the usual test types; ignoring the valuable assistance of the ophthalmoscope.

Simple Myopic Astigmatism.

136. This being simple, as we have only one meridian in error (**133**), the other meridian being emmetropic. And the name of simple myopic astigmatism would lead us to suppose that the faulty meridian was erring in the direction of myopia.

This is just the case.

Therefore in simple myopic astigmatism we have one meridian myopic and the other meridian emmetropic.

Which meridian then do we expect would err in the direction of myopia ?

Clearly the vertical meridian, because :

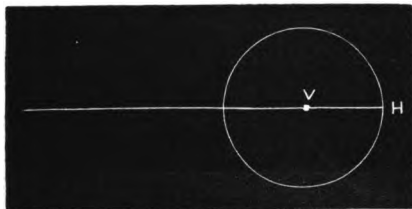
(A) Myopia is always associated with the idea of too much convexity of the refracting media.

(B) The vertical meridian, being naturally more convex than the horizontal, is that meridian which we should expect would assume a condition of too great convexity.

Hence, in simple myopic astigmatism we find :

- (1) The vertical meridian myopic.
- (2) The horizontal meridian emmetropic (Fig. 26).

FIG. 26.—SIMPLE MYOPIC ASTIGMATISM.



V. = Myopic focus of vertical meridian.

H. = Emmetropic focus of horizontal meridian.

Simple Hypermetropic Astigmatism.

137. This also being simple astigmatism we have again one meridian in error, the other being emmetropic.

And its name would lead us to suppose that the faulty meridian was erring in the direction of hypermetropia.

This is the case.

So in simple hypermetropic astigmatism one meridian is hypermetropic, the other is emmetropic.

Which meridian then do we expect would err in the direction of hypermetropia ?

Clearly the horizontal meridian, because :

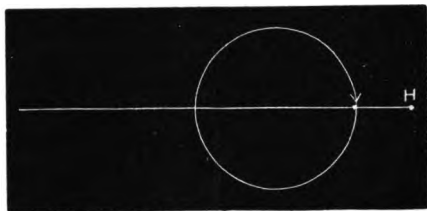
(A) Hypermetropia is associated with the idea of *too little* convexity of the refracting media.

(B) The horizontal meridian, being naturally less convex than the vertical meridian, is that meridian which we should expect *would* assume a condition of too little convexity.

Hence, in simple hypermetropic astigmatism we find :

- (1) The vertical meridian is emmetropic.
- (2) The horizontal meridian is hypermetropic (Fig. 27).

FIG. 27.—SIMPLE HYPERMETROPIC ASTIGMATISM.



V. = Emmetropic focus of vertical meridian.

H. = Hypermetropic focus of horizontal meridian.

138. Here it may be as well to mention that although we talk of the two faulty meridians of the cornea as being the vertical and horizontal meridians,

yet we must remember that they are seldom situated exactly according to their names. But the point to remember in connection with them is that, however they may deviate respectively from the direction which their name would imply, yet they are always at right angles to each other in all cases of astigmatism.

How the exact directions of the meridians can be arrived at will be explained further on.

CHAPTER X

COMPOUND ASTIGMATISM

We have said before (134) that there are two kinds of compound astigmatism :

- (1) Compound myopic astigmatism.
- (2) Compound hypermetropic astigmatism.

And also (134) that in all cases of compound astigmatism both meridians are faulty in their refraction. We will first consider :

Compound Myopic Astigmatism.

139. This being compound astigmatism, both meridians are in error ; and its name, compound *myopic* astigmatism, might lead us to suppose that both the faulty meridians erred in the direction of myopia.

This is just what they do in compound myopic astigmatism, for in this error of refraction both meridians are myopic.

But these myopic meridians must be myopic in different degrees ; for if both were myopic to the *same* extent we should have myopia pure and simple without any astigmatism.

Therefore, in compound myopic astigmatism one meridian must be more myopic than the other.

Hence it is a kind of irregular myopia, but differing from it by the fact that one meridian is more myopic than the other.

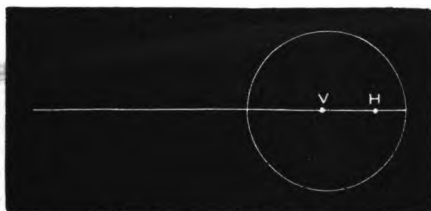
And which of the two meridians should we expect to be the most myopic?

Clearly the vertical meridian.

Because, since the term myopia always conveys an idea of too great convexity, and since the vertical is naturally more convex than the horizontal meridian, the vertical starts in front of its fellow meridian (horizontal) in the race for the joint development of the myopic astigmatism.

It is only reasonable, therefore, to expect, when both meridians have arrived at the condition of myopia, that the most myopic meridian would be that one

FIG. 28.—COMPOUND MYOPIC ASTIGMATISM.



V. = Myopic focus of vertical meridian.

H. = Myopic focus of horizontal meridian.

which, by reason of its greater comparative convexity, started with a tendency to myopia.

140. Therefore, in compound myopic astigmatism

we have both meridians myopic, and of the two the vertical is the most myopic.

Compound Hypermetropic Astigmatism.

141. This being compound astigmatism, both meridians are in error, and its name, compound hypermetropic astigmatism, might lead us to suppose that both the faulty meridians erred in the direction of hypermetropia.

This is just what they do in compound hypermetropic astigmatism, for in this error of refraction both meridians are hypermetropic.

And just as in compound myopic astigmatism both meridians are myopic, so in this compound hypermetropic astigmatism both meridians are hypermetropic, but in different degrees, or else we should have pure and simple hypermetropia without any astigmatism.

142. Therefore, in compound hypermetropic astigmatism, one meridian is more hypermetropic than the other, and hence, just as compound myopic astigmatism was said to be an irregular form of myopia (139), so compound hypermetropic astigmatism may be considered as an irregular form of hypermetropia, but differing from pure hypermetropia by the fact that one meridian is more hypermetropic than the other.

And which of the two meridians should we expect to be the most hypermetropic?

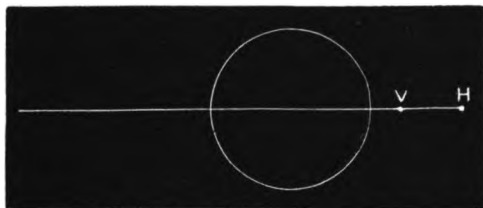
The horizontal meridian, of course; because since the term hypermetropia always conveys an idea of

deficiency in refractive power, that is an idea of flatness of the refracting media, and since the horizontal is naturally flatter than the vertical meridian, it follows that the horizontal meridian has the start, so to say, over its fellow meridian in the race for the joint development of the hypermetropia which they are both afflicted with in this compound hypermetropic astigmatism.

It is only reasonable, therefore, to expect, when both meridians have arrived at the condition of hypermetropia, that the *most* hypermetropic meridian should be that meridian which, by reason of its greater comparative flatness, started with a tendency to hypermetropia.

143. Therefore, in compound hypermetropic astig-

FIG. 29.—COMPOUND HYPERMETROPIC ASTIGMATISM.



V. = Hypermetropic focus of vertical meridian.

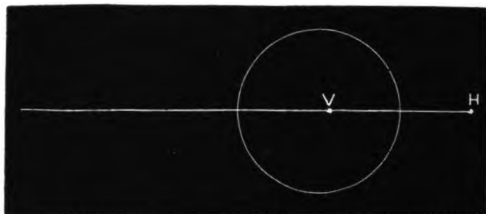
H. = Hypermetropic focus of horizontal meridian.

matism we have both meridians hypermetropic, and of the two the horizontal is the most hypermetropic.

144. In mixed astigmatism we have both meridians at fault in their refraction, but each in a different direction, for the vertical, naturally curved meridian has

become more curved, *i. e.* more myopic; and the horizontal, naturally flat meridian has become more flat, *i. e.* more hypermetropic, as explained by Fig. 30.

FIG. 30.—MIXED ASTIGMATISM.



V. = Myopic focus of vertical meridian.

H. = Hypermetropic focus of horizontal meridian.

CHAPTER XI

SIMPLE MYOPIC ASTIGMATISM

THE diagnosis and treatment of simple astigmatism, whether myopic or hypermetropic, is easy when once our suspicion of the existence of astigmatism has been aroused.

145. We are led to suspect the presence of astigmatism when (supposing that there is no evidence of organic deep-seated mischief in the eye) we are unable, by any trial lenses, to effect anything more than a trivial improvement of distant vision ; or when, as sometimes happens, a + lens seems to improve the distant vision almost as much as a - lens.

146. Suspecting then the presence of astigmatism, we place the patient at a distance of 6 metres from the ordinary distant test type and at the same distance from the astigmatic clock, and the direction of the most distinct lines on the clock face will point out the direction of the most erroneous meridian, and consequently the meridian which is at right angles to the most erroneous one will be the *least* erroneous meridian.

With the test type we find, say :

$$V. = \frac{6}{18}.$$

With the clock we find :

Vertical lines (from 12 o'clock to 6 o'clock) distinct.

Horizontal lines indistinct.

From this we learn :

(1) That the vertical meridian is ametropic.

(2) That the horizontal meridian is emmetropic ;
or, at all events, that the vertical meridian which shows the most distinct lines deviates more from emmetropia than does the horizontal.

We now fix in the trial frame a stenopaic slit, which is a wooden or metallic disc with an oblong slit in it of about 2 mm. breadth.

Of course when the slit is vertical then rays of light can pass only through the vertical meridian of the cornea ; and when the slit is horizontal then rays of light can pass only through the horizontal meridian of the cornea.

We now gently rotate the disc until we bring it into such a position as gives the best distant vision of the test types.

147. The direction of the slit when the best distant vision is obtained will point out the direction of the most emmetropic meridian. We will suppose this to be the horizontal meridian.

148. With the slit then in the horizontal position we note whether the vision is normal, for if $V. = \frac{6}{6}$, and it is not impaired when a low + sphere is placed before it, then we know that the horizontal meridian is emmetropic.

Having proved the horizontal meridian to be

emmetropic we now rotate the disc so as to bring the slit into the vertical position, thereby bringing the vertical meridian to the test, and if it does not equal $\frac{6}{18}$ we then know that the vertical meridian is erroneous and we proceed to correct it, first noting its vision for the distant type and for the clock face.

Suppose we find, say :

- (1) $V. = \frac{6}{18}$.
- (2) Vertical lines of the clock are dark.
- (3) Horizontal lines of the clock are indistinct.

Then, since the horizontal meridian is emmetropic, as shown by 148, and confirmed by the indistinctness of the horizontal lines, and since the vertical meridian is erroneous, as shown by $V. = \frac{6}{18}$ and by the distinct vertical lines on the clock, our opinion will be that we are dealing with a case of simple astigmatism with an erroneous vertical meridian.

We now proceed to correct the vertical meridian, and keeping the slit vertically in the direction of the erroneous meridian we place a convex sphere, say + 1 D., in front of it with the result that now :

(1) $V. = \frac{6}{36}$ instead of $\frac{6}{18}$, so vision has been made worse.

- (2) Vertical lines still more distinct.

The + sphere, therefore, has rendered matters worse.

We therefore try a - sphere, say - 1 D., with the slit still vertical, and we find :

(1) $V. = \frac{6}{9}$ instead of $\frac{6}{18}$, so the lens has improved vision.

(2) Vertical and horizontal lines are about equally indistinct, the vertical having become less distinct and the horizontal more so.

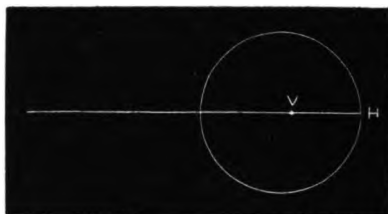
We now try a -2 D. sphere and find :

(1) $V. = \frac{9}{8}$, i. e. is correct.

(2) Vertical and horizontal lines are all equally distinct.

Thus, a -2 D. sphere, acting through the vertical slit, has corrected the vertical meridian, and consequently a -2 D. cylinder with axis horizontal will correct this meridian. We have thus proved that the vertical meridian is myopic -2 D., and as the horizontal meridian was emmetropic, we have been dealing with a case of simple myopic astigmatism with the vertical meridian in front of the horizontal (Fig. 31).

FIG. 31.—SIMPLE MYOPIC ASTIGMATISM.



It will be observed that the principle on which we have proceeded has been to find out the least erroneous meridian, and, if necessary, proceed to correct it, but if we find it emmetropic we then test the meridian which is at right angles to the emmetropic one. And if astigmatism exists this meridian must be erroneous ;

and we are dealing with a case of simple astigmatism, but whether it is simple myopic or simple hypermetropic is of course decided by noting that lens which, acting on the erroneous meridian, renders vision normal.

149. Hence our rules will be :

(1) By means of the slit find out the least erroneous meridian, and if vision is not normal then proceed to correct the meridian by means of + or - spheres.

(2) Note the number of dioptries of the correcting sphere.

(3) Rotate the slit so as to place its direction at right angles to the least erroneous meridian ; consequently the slit will now be in the direction of the *most* erroneous meridian ; then proceed to correct this meridian by means of + or - spheres.

(4) Always commence the correction of any erroneous meridian by using + spheres, and these failing to improve vision, then proceed to use - spheres.

CHAPTER XII

SIMPLE HYPERMETROPIC ASTIGMATISM

150. Suspecting astigmatism, for the reasons given in Section 145, we proceed as in Section 146, and test the eye with test type, and find, say :

$$V. = \frac{6}{24}.$$

With the clock we find :

Vertical lines indistinct.

Horizontal (9 o'clock to 3 o'clock) distinct.

From this we learn :

(1) That the vertical meridian is emmetropic.

(2) That the horizontal meridian is in error; the distinct lines showing that it deviates more from emmetropia than does the vertical meridian.

Now fix the stenopaic slit and rotate it so as to bring it into such a position as gives the most distinct vision of the distant test type.

151. The direction of the slit will point out the direction of the most emmetropic meridian. We will suppose this to be the vertical one.

We therefore fix the slit in a vertical position and note whether vision is normal; for if $V. = \frac{6}{8}$, and

it is not impaired when a low + sphere is placed before it, then we know that the vertical meridian is emmetropic.

Having proved the vertical meridian to be emmetropic, we then proceed to test the horizontal by bringing the slit into a horizontal position.

Suppose we find, with the slit horizontal :

- (1) $V. = \frac{6}{24}$.
- (2) Vertical lines of clock indistinct.
- (3) Horizontal dark.

Then, since the vertical meridian is emmetropic, as shown by $V = \frac{6}{24}$ and confirmed by the indistinctness of the vertical lines, and since the horizontal meridian is erroneous, as shown by $V. = \frac{6}{24}$ and by the dark horizontal lines on the clock, our opinion will be that we have before us a case of simple astigmatism with an erroneous horizontal meridian.

We now proceed to correct this erroneous horizontal meridian. Keeping the slit then in the direction of the horizontal meridian we place a convex sphere, say +1 D., in front of it, with the result that :

- (1) $V. = \frac{6}{12}$, so the lens has improved vision.
- (2) Vertical lines less indistinct.
- (3) Horizontal lines less dark and distinct.

We now, since a + 1 D. sphere improved vision, try a + 2 D. sphere, and find :

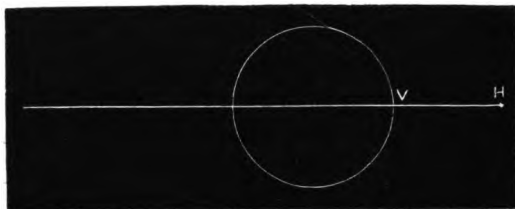
- (1) $V. = \frac{6}{6}$, i. e. is correct.
- (2) Vertical and horizontal lines are all equally distinct.

Thus a + 2 D. sphere acting through the horizontal slit has corrected the horizontal meridian, and

consequently a $+2$ D. cylinder axis vertical will correct the horizontal meridian.

We have now proved that the horizontal meridian is hypermetropic $+2$ D., and as the vertical was emmetropic we have been dealing with a case of simple hypermetropic astigmatism with the focus of the horizontal meridian behind that of the vertical (Fig. 32).

FIG. 32.—SIMPLE HYPERMETROPIC ASTIGMATISM.



CHAPTER XIII

COMPOUND MYOPIC ASTIGMATISM

152. Suspecting the presence of astigmatism, for reasons given in Section 145, with the test type we find :

$V. = \frac{6}{36}$, badly.

With the clock :

Vertical lines dark and distinct.

Horizontal indistinct.

From this we learn :

(1) That the vertical meridian is erroneous.

(2) That the horizontal meridian is emmetropic, or all events that the vertical meridian which shows the most distinct lines, deviates more from emmetropia than does the horizontal meridian.

With the slit horizontal $V. = \frac{6}{18}$.

With the slit vertical $V. = \frac{6}{60}$.

Therefore, this again tells us that the horizontal meridian is the *least* erroneous of the two; and therefore that the meridian at right angles to it, viz. the vertical, is the most erroneous.

Then fixing the slit horizontally we proceed to correct the horizontal least erroneous meridian.

We find that with the slit horizontal :

$$V. = \frac{6}{18}.$$

We then try a + 1 D. sphere, and find :

$$V. = \frac{6}{80}, \text{ i. e. the error is made worse.}$$

So we try a - 1 D. sphere, and with it :

$$(1) V. = \frac{6}{9}.$$

(2) Vertical and horizontal lines are all fairly distinct.

With a - 2 D. sphere, we find :

$$(1) V. = \frac{6}{9}.$$

(2) All lines of the clock equally distinct and clear.

Therefore a - 2 D. sphere has corrected the horizontal meridian, which consequently had - 2 D. of myopia.

Then fixing the slit vertically (in the direction of the most erroneous meridian) we find :

$$(1) V. = \frac{6}{80}.$$

(2) Vertical lines darkest and most distinct.

(3) Horizontal lines indistinct.

Keeping the slit vertically we proceed to correct the vertical meridian.

We place a + 1 D. sphere in the frame and find that no type is visible. Therefore the + lens has made vision worse.

Consequently we fix - 1 D., and find now :

$$(1) V. = \frac{6}{24}, \text{ i. e. vision is improved.}$$

(2) Vertical lines dark and distinct.

Horizontal less indistinct.

We change now to - 2 D. sphere, and find :

$$(1) V. = \frac{6}{18}, \text{ i. e. still more improved.}$$

(2) Vertical lines dark and distinct.

Horizontal lines still less indistinct.

A - 3 sphere effects still further improvement, for with it :

(1) $V. = \frac{8}{9}$.

(2) Vertical and horizontal lines are all fairly distinct.

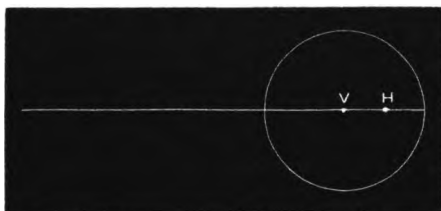
And a - 4 D. sphere makes :

(1) $V. = \frac{8}{9}$.

153. Vertical and horizontal lines all clear and distinct. Therefore a - 4 D. sphere has corrected the vertical meridian, which consequently had - 4 D. of myopia; and we have seen that the horizontal meridian had - 2 D. of myopia.

Therefore, both meridians being myopic, we have

FIG. 33.—COMPOUND MYOPIC ASTIGMATISM.



been dealing with a case of compound myopic astigmatism with :

Vertical meridian = - 4 D.

Horizontal meridian = - 2 D.

Which would be written thus, supposing that the right eye has been tested :

$$\text{R.} \quad \begin{array}{|c} -4 \text{ D.} \\ \hline -2 \text{ D.} \end{array}$$

The cross lines representing the two meridians.

And supposing that the amounts of error in the two meridians remained the same after that we had paralysed the accommodation with atropine, we should correct the errors as follows: we should correct the least erring meridian with a sphere, and the other with a cylinder; therefore in this case our correction would be - 2 D. sphere $\subset^*$ - 2 D. cylinder axis horizontal.

It is evident that the - 2 D. sphere fully corrects the horizontal meridian, and also will at the same time correct 2 D. out of the 4 D. of the myopia of the vertical, leaving only 2 dioptries (instead of 4 D.) of the vertical to be corrected by the cylinder.

A little consideration will show why in such a case we should fail to materially improve vision by the spheres alone.

For a - 2 D. sphere would fully correct the horizontal, and would partially correct the vertical.

A - 3 D. sphere would still further improve the vertical meridian, but would have over corrected the horizontal myopic meridian so that it would have become hypermetropic + 1 D.

A - 4 D. sphere would have fully corrected the vertical meridian, but would have increased the over correction of the horizontal meridian which would have become hypermetropic + 2 D.

* $\subset$ means combined with.

CHAPTER XIV

COMPOUND HYPERMETROPIC ASTIGMATISM

154. Suspecting the presence of astigmatism, for reasons given in Section 145, with the test type we find :

(1) $V = \frac{6}{80}$.

With the clock :

(2) Vertical lines indistinct.

Horizontal somewhat darker.

From this we learn that the horizontal meridian which shows the most distinct lines deviates more from emmetropia than does the vertical meridian.

With the slit vertical, $V. = \frac{6}{18}$.

With the slit horizontal, $V. = \frac{6}{80}$, badly.

Clearly, then, the vertical meridian is the least in error and therefore the horizontal is the most erroneous.

Then fixing the slit vertically we proceed to correct the vertical least erroneous meridian. We find :

(1) $V. = \frac{6}{18}$.

(2) Vertical lines dark and distinct.

(3) Horizontal lines indistinct.

With a + 1 D. sphere we find :

(1) $D. = \frac{6}{18}$.

(2) Vertical lines dark.

(3) Horizontal getting darker.

Therefore a + 1 D. sphere improves vision, so we try a + 2 sphere and we find :

(1) $V = \frac{6}{80}$.

(2) Vertical and horizontal lines equally clear and distinct.

Therefore a + 2 D. sphere has corrected the vertical meridian, which consequently had + 2 D. of hypermetropia.

Then fixing the slit horizontally we find :

(1) $V = \frac{6}{80}$ badly.

(2) Vertical lines almost invisible.

(3) Horizontal lines dark.

Keeping the slit horizontal, we proceed to correct the horizontal meridian.

We place a + 1 D. sphere in the trial frame and find :

(1) $V = \frac{6}{80}$.

(2) Vertical lines less indistinct.

(3) Horizontal lines dark.

With a + 3 D. sphere we find :

(1) $V = \frac{6}{80}$.

(2) Vertical lines becoming darker.

(3) Horizontal lines still dark.

Therefore the + 3 D. sphere has improved vision.

With a + 4 D. sphere we find :

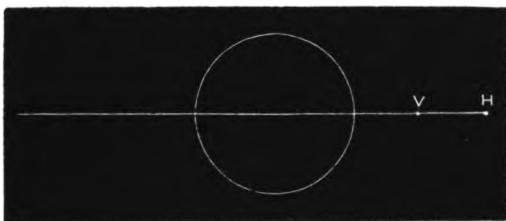
(1) $V = \frac{6}{80}$.

(2) Vertical and horizontal lines clear and distinct.

155. Therefore a + 4 D. sphere has corrected the horizontal meridian, which consequently had + 4 D. of

hypermetropia ; and we have seen that the vertical meridian had $+ 2$ D. of hypermetropia, and therefore, since both the meridians are hypermetropic, we have

FIG. 34.—COMPOUND HYPERMETROPIC ASTIGMATISM.



been correcting a case of compound hypermetropic astigmatism with :

Vertical meridian $\Rightarrow + 2$ D.

Horizontal meridian $= + 4$ D.

Which would be written thus, supposing that the right eye has been tested :

$$\text{R. } \begin{array}{c} + 2 \text{ D.} \\ | \\ \text{---} \end{array} + 4 \text{ D.}$$

The cross lines representing the meridians.

And supposing that the amount of error in the two meridians remained the same after that we had paralysed the accommodation with atropine, we should correct the errors as follows ; we should correct the least erroneous meridian by a sphere and the other by a cylinder, and therefore, in this case, the correction would be $+ 2$ D. sphere $\odot + 2$ D. cylinder axis vertical.

It is evident that the $+ 2$ D. sphere will fully correct

the vertical meridian, and also will at the same time correct 2 D. out of the 4 D. of the hypermetropia of the horizontal meridian, leaving only 2 dioptries (instead of 4 D.) of the horizontal to be corrected by the cylinder.

It is evident also that no sphere alone would have materially improved vision, because the two meridians require unequal corrections, but a sphere of course would alter all meridians to an equal extent.

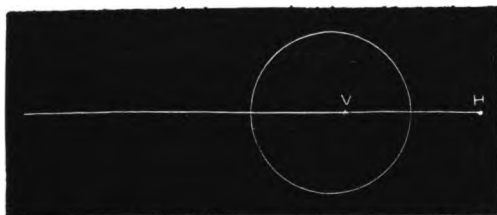
CHAPTER XV

MIXED ASTIGMATISM

156. We have hitherto dealt with cases of astigmatism in which one meridian has been more erroneous than the other. We will now consider a case of mixed astigmatism in which the two meridians may be equally faulty, one being myopic and the other hypermetropic. Of course, if they were either equally myopic or equally hypermetropic, we should not have any astigmatism, but the case would be one of ordinary myopia or ordinary hypermetropia.

Suppose the vertical meridian is myopic -2 D.,

FIG. 35.—MIXED ASTIGMATISM.



and the horizontal meridian hypermetropic $+2$ D., in such a case vision would be equally faulty whether

the vertical or the horizontal meridian is tested, and therefore we cannot follow out our plan of correcting the least faulty meridian first, inasmuch as the errors in each are of the same degree. It remains therefore in such a case to select one meridian and correct that one, doing the same afterwards with the other meridian.

We will first take the vertical meridian, placing the slit vertically, and fixing + 1 D. sphere in the frame we find :

$$V = \frac{6}{8}.$$

With + 2 D. letters are hardly visible. Therefore a + lens makes vision worse.

With - 1 D. sphere we find :

$$(1) V. = \frac{6}{8}.$$

(2) Vertical and horizontal lines are fairly dark ; horizontal the darker.

With - 2 D. sphere we find :

$$(1) V. = \frac{6}{8}.$$

(2) Vertical and horizontal lines all equally distinct.

Therefore the vertical meridian is corrected by - 2 D. sphere.

Now place the slit horizontally and we find that + 1 D. sphere improves the vision and that + 2 D. sphere renders :

$$(1) V. = \frac{6}{8}.$$

(2) Vertical and horizontal lines equally clear and distinct.

Thus the vertical meridian is corrected by a - 2 D. sphere and the horizontal by a + 2 D. sphere.

157. One meridian, therefore, has - 2 D. of myopia

and the other + 2 D. of hypermetropia, and we have been correcting a case of mixed astigmatism with :

Vertical meridian = - 2 D.

Horizontal meridian = + 2 D.

Which would be written thus, supposing that the right eye has been tested :

$$\text{R.} \quad \begin{array}{c|c} & -2 \text{ D.} \\ \hline & +2 \text{ D.} \end{array}$$

The cross lines representing the meridians.

And if, when under the influence of atropine, the meridians still showed the same amount of error, and if we followed our usual plan, we should correct the least erroneous meridian by a sphere and the other by a cylinder. But in this case the meridians are equally erroneous.

Therefore it will serve to illustrate another rule, viz. :

158. If possible order a - cylinder to be ground on to a + sphere, rather than a + cylinder to be ground on to a - sphere.

Therefore our prescription for the optician would be + 2 D. sphere $\ominus$ - 4 D. cylinder axis horizontal.

It is almost self-evident why it was that no sphere alone was found to improve vision to any extent, because in the same proportion as a + sphere improved the horizontal meridian, just in the same degree did it make the vertical more erroneous ; and with a - sphere the vertical was improved at the expense of the horizontal.

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